Land Cover and Land Use Change

An Overview of Recent MODLAND Results

Chris Justice, UMD

Alan Strahler, BU

John Townshend, UMD

Land Cover and Land Use Change Product Families:

- Strahler:
  - Quarterly Land Cover (1km)
    - IGBP discrete classes with uncertainty indices
- Townshend:
  - Vegetation Continuous Fields (500m)
    - Sub-pixel land cover components based on annual phenology
  - Vegetative Cover Conversion (250m)
    - Monthly alarm for anthropogenic land cover change
- Justice:
  - Active Fire (1km and 10km / 0.5° CMG)
    - Daily and 8-day summaries
  - Burned Area (500m)
    - Experimental product

MODLAND land cover and land use change research addresses key ESE science questions:

- Variability:
  - *How are global ecosystems changing?*
- Forcing:
  - *What changes are occurring in global land cover and land use, and what are their causes?*
  - *How is the Earth's surface being transformed and how can such changes be use to predict future changes?*
- Response:
  - *What are the effects of regional pollution on the global atmosphere, and the effects of global chemical and climate changes on regional air quality?*
- Consequences:
  - *What are the consequences of land cover and land use change for the sustainability of ecosystems and economic productivity?*
- Prediction:
  - *How well can the cycling of carbon through the Earth system be modeled, and how reliable are predictions of future atmospheric concentrations of carbon dioxide and methane by these models?*

Quarterly 1km Land Cover

M.A. Friedl [1] and Alan Strahler [1]

[1] Department of Geography, Boston University
Boston, Massachusetts

Global Land Cover Classification Overview

- **Objective:**
  - Provide a simple land-cover categorization
    - GCM, hydrologic, and carbon models
    - 1 km spatial resolution
    - Quarterly
- **Features:**
  - Categorizes land cover following **IGBP-DIS** scheme
  - Relies on spectral, spatial, temporal, directional information
  - Supervised, non-parametric classification algorithms

Land Cover Input Database

(Month Aggregated/Composited Database)

- ***Surface Reflectance***
  - View-angle corrected (nadir) surface reflectance, 7 land bands
- ***Plus:***
  - ***Spatial Texture from 250-m Band 2***
    - Standard deviation-to-mean ratio in Band 2 (near-infrared), maximum value composite in 32-day period
  - ***Vegetation Index***
    - MODIS Vegetation Index, maximum value composite
  - ***Snow Cover***
    - MODIS Snow Cover Product, number of days with snow cover
  - ***Land Surface Temperature***
    - MODIS Land Surface Temperature, maximum value composite
  - ***Directional Information***
    - Bidirectional reflectance model choices from BRDF product
  - Artificial neural networks, decision trees
  - Global test sites
- **Release date – April 1, 2001**

Classification Algorithms

- **Supervised Approach**
  - Required to provide robust repeatable results
  - Relies heavily on input training database
- **Non-Parametric Algorithms**
  - Artificial neural networks
    - ***Fuzzy ARTMAP***—Uses Adaptive Resonance Theory
  - Decision Trees
    - ***C5.0: Univariate Decision Tree***
- **Boosting:**
  - Provides explicit statistical framework (GAM; Friedman et al. 2000; Annals of Statistics)

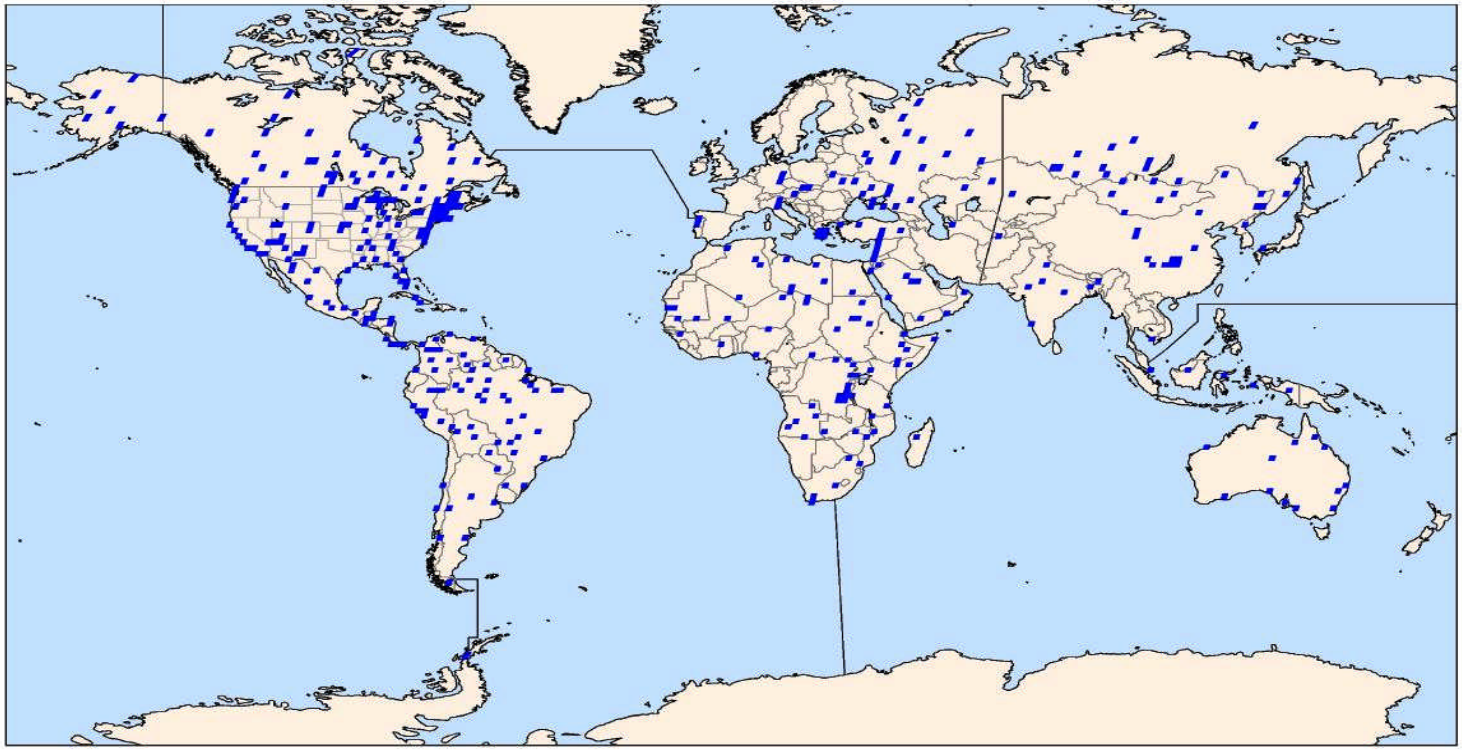
STEP Database

- STEP:
  - System for Terrestrial Ecosystem Parameterization
  - **Manually interpreted from TM and ancillary data**
    - Parameterized using STEP
  - Currently includes ~920 sites globally

- Key STEP Parameters
  - Life form, height, cover fraction, # of layers
  - Leaf type, phenology, periodicity, physiognomy of dominants in layers
  - Elevation, moisture regime, perturbation
  - Simple description of site and type

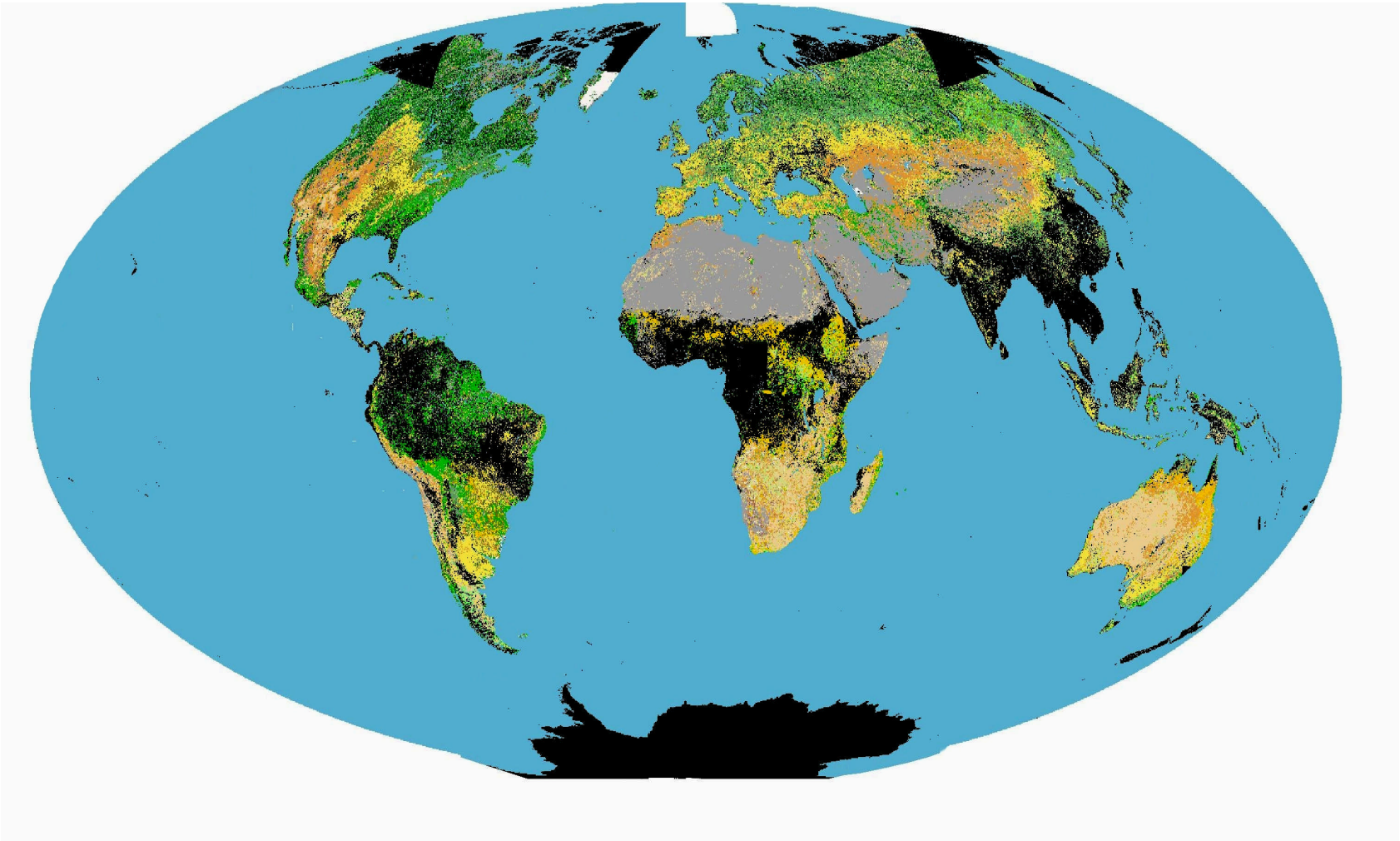
- **Allows application of many different land cover labeling schemes by inference of label from parameters in database**

Global Test Site Network

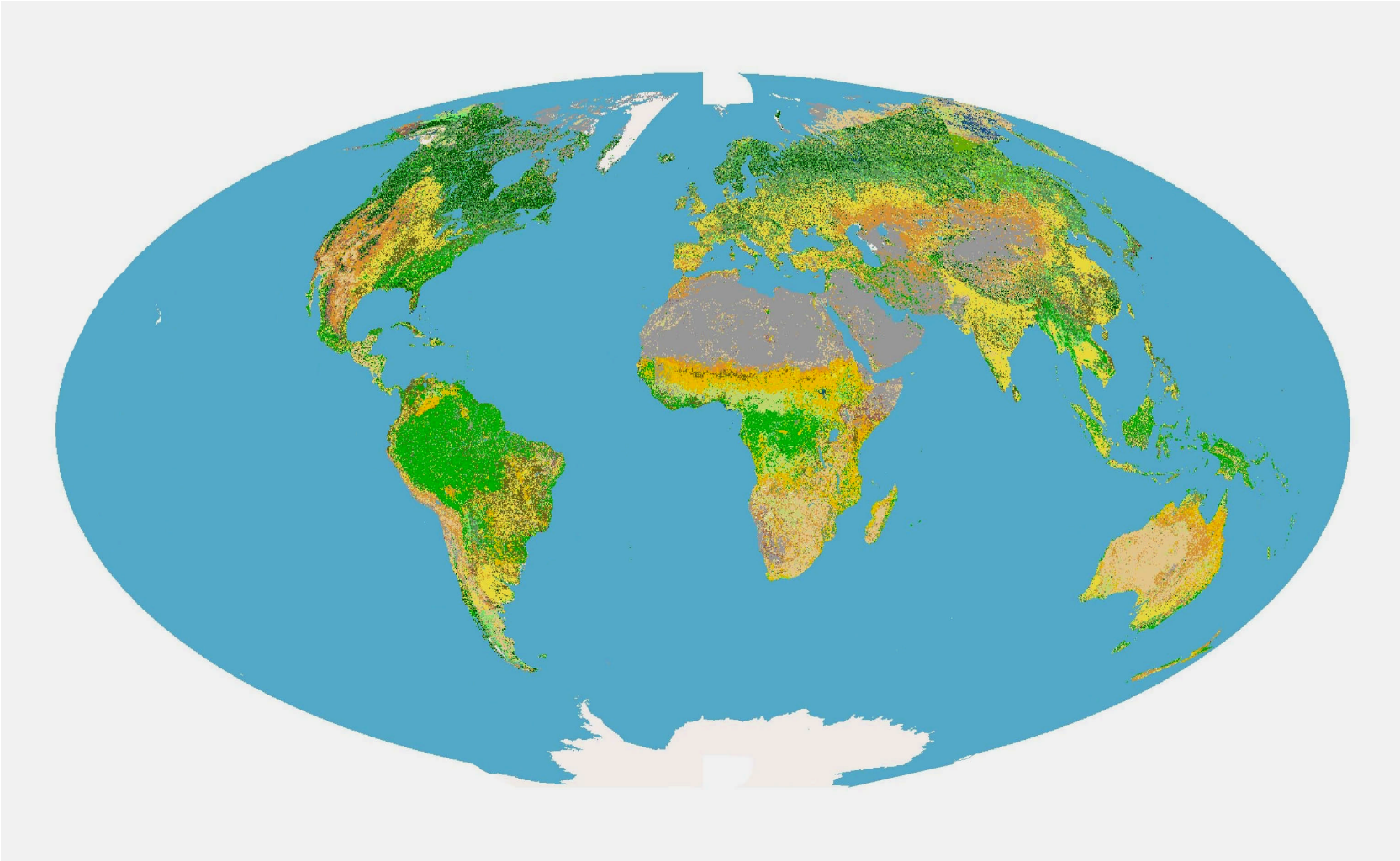


Initial Results From 2 Global Views

(July 11 and August 25 2000)

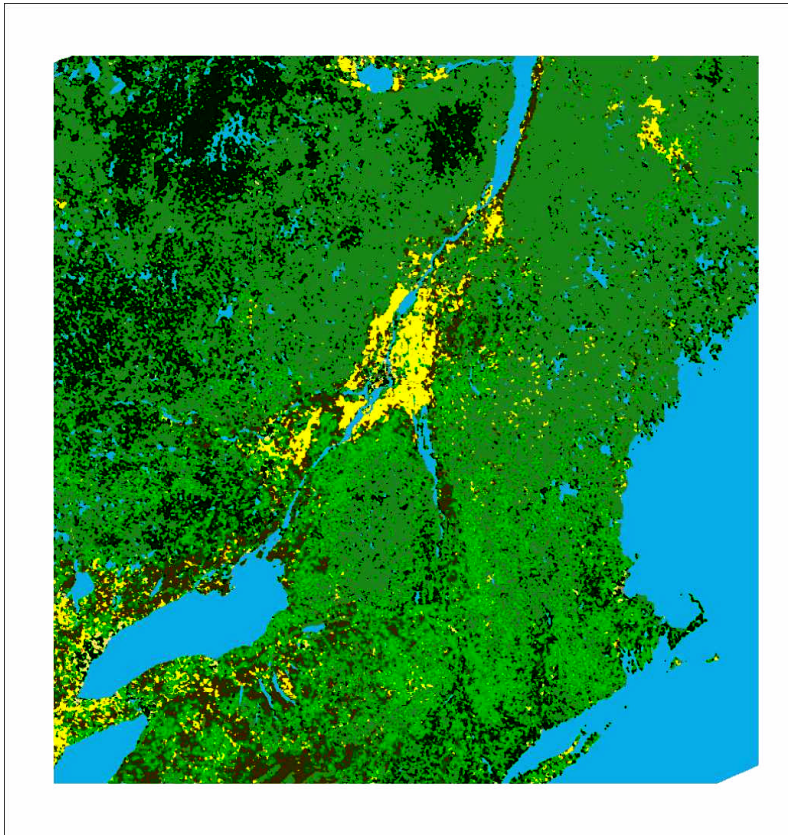


MODIS Classification Merged with EDC (AVHRR) At-Launch Product

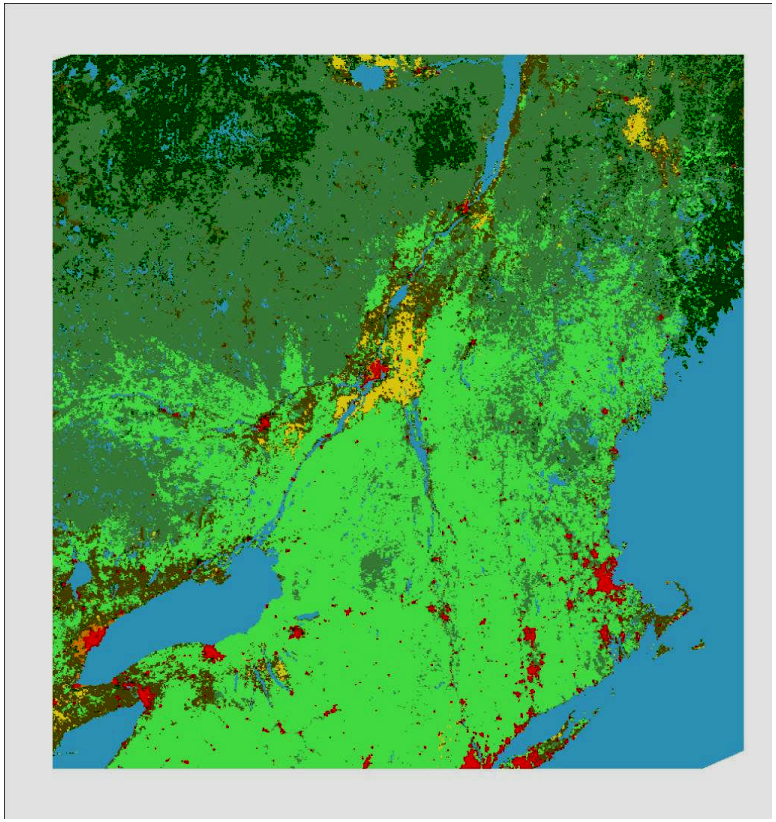


Regional View – New England

- From MODIS

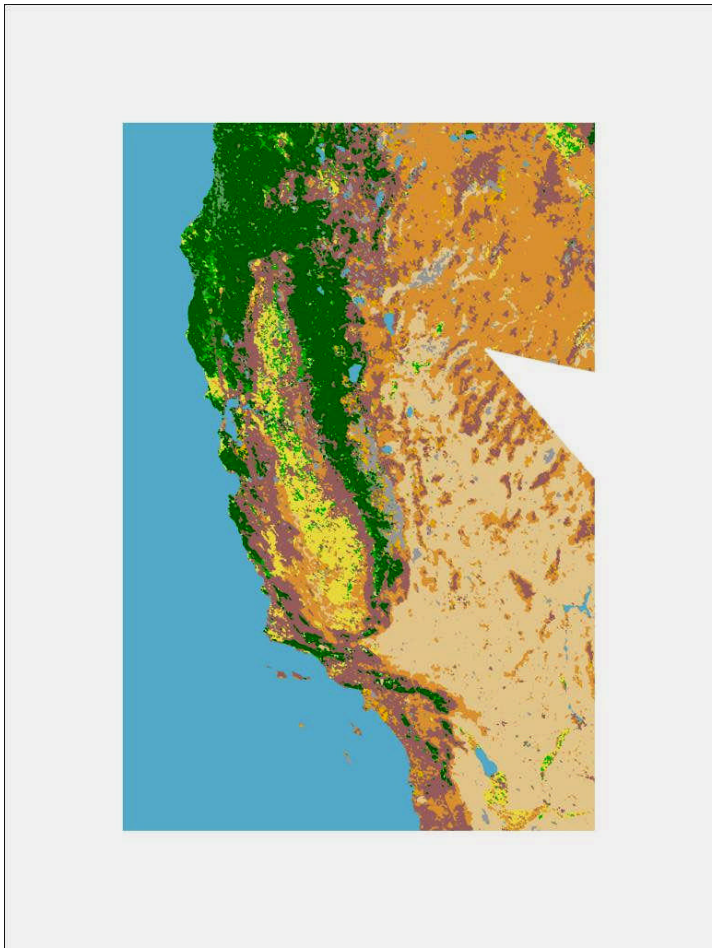


- EDC AT-Launch

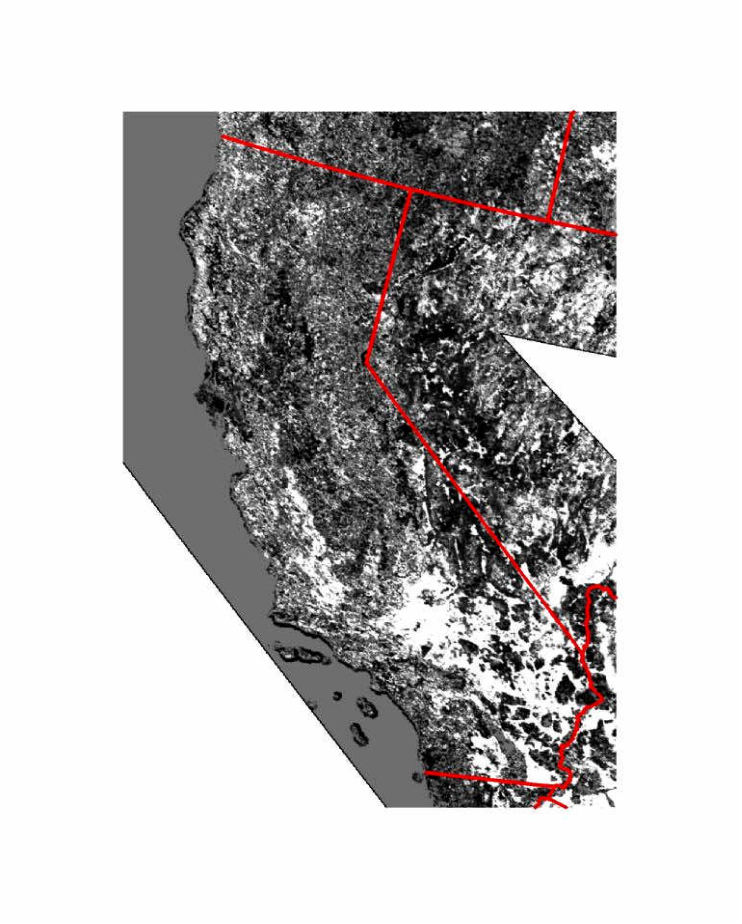


Classification Confidence

- MODIS Classification



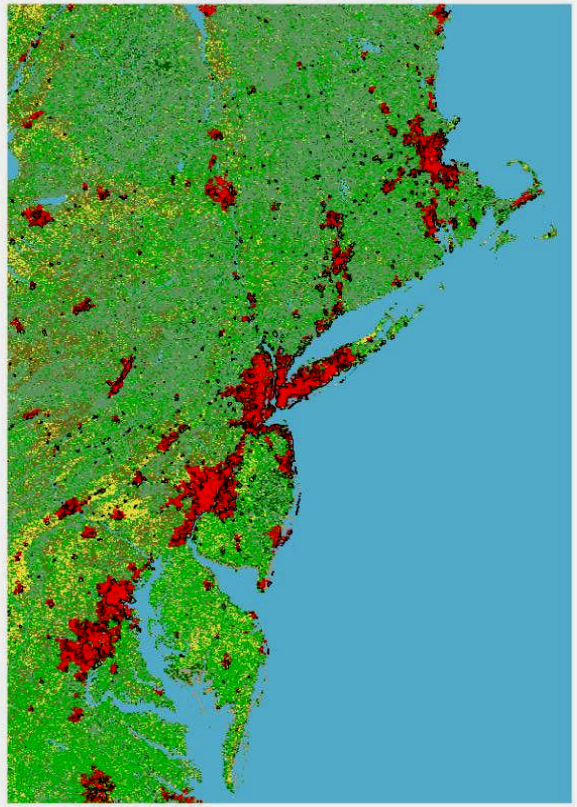
- Classification Confidence



Mapping Urban Areas – Merging City Lights Data with MODIS

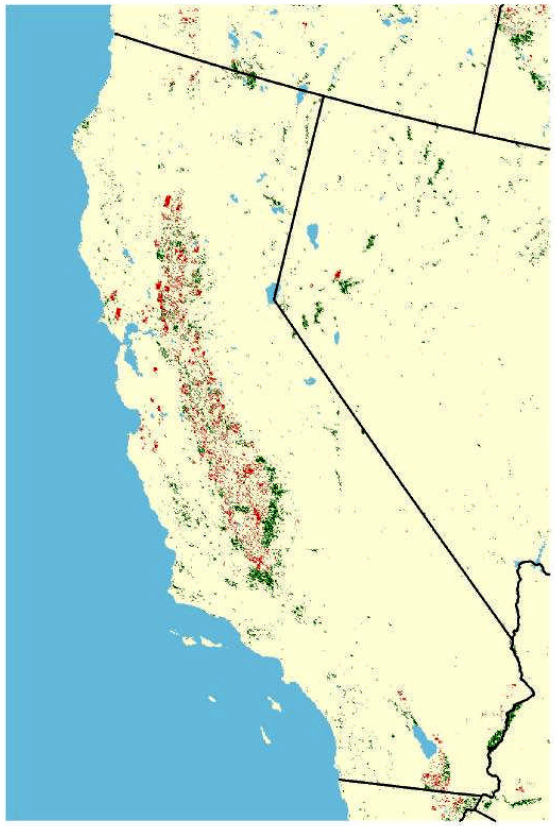
- MODIS Data Only

- MODIS + City Lights



Inclusion of Prior Probabilities

(McIver and Friedl; submitted to RSE)



- Theory derived from boosting allows ancillary information to be included using Bayes rule
  - Red = Natural vegetation to agriculture
  - Green = Agriculture to natural vegetation

Vegetation Continuous Fields and Vegetation Cover Conversion

John Townshend [1,2], Ruth DeFries [1,3], Xiwu Zhan [1], Charlene DiMiceli [1], Matt Hansen [1], Rob Sohlberg [1], Mark Carroll [3], Jill Eastman [1]

[1] Department of Geography,
[2] UMIACS,
[3] ESSIC,
University of Maryland College Park, MD

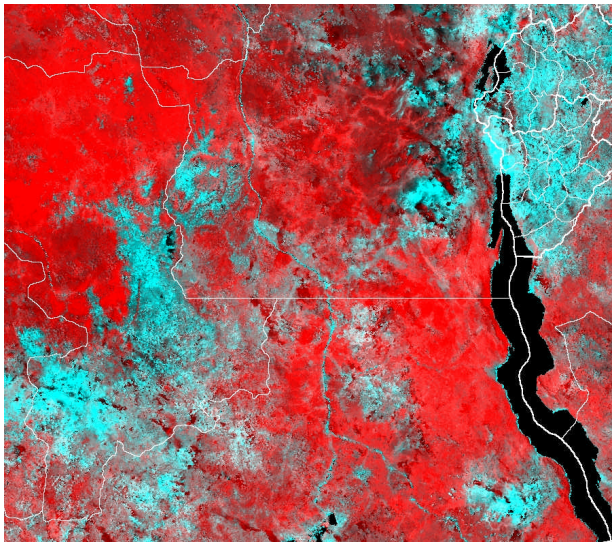
Vegetation Continuous Fields depiction of Land Cover

- Overcome fixed boundaries between classes inherent in classification approach
- Independent of strict class type definitions
- Possible to apply temporally to identify changes in % cover
- Derived from MODIS imagery with calibration and validation from high resolution data

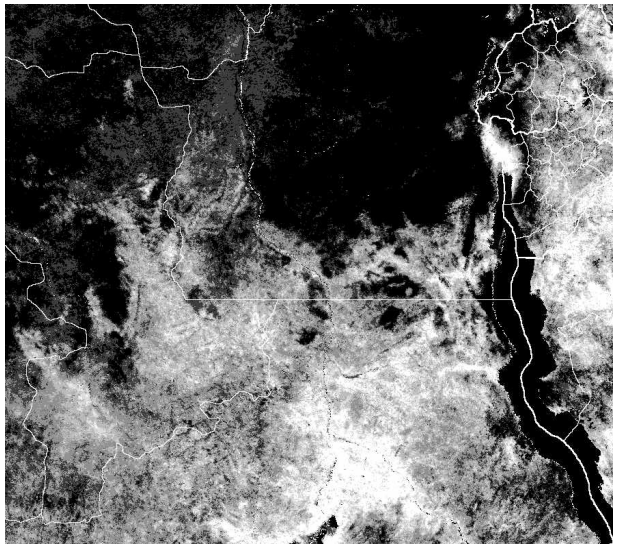
Methodology

- Use continuous training data from high-resolution datasets scaled to MODIS resolutions
- Create temporal metrics describing vegetation phenology
- Employ regression tree using percent cover training as dependent variable and metrics as independent variables
- Scale nodes using simple regression/mixture modeling techniques
- Current layers include tree, tree leaf type, tree leaf longevity, bare ground and herbaceous covers

Annual metrics for characterizing land cover

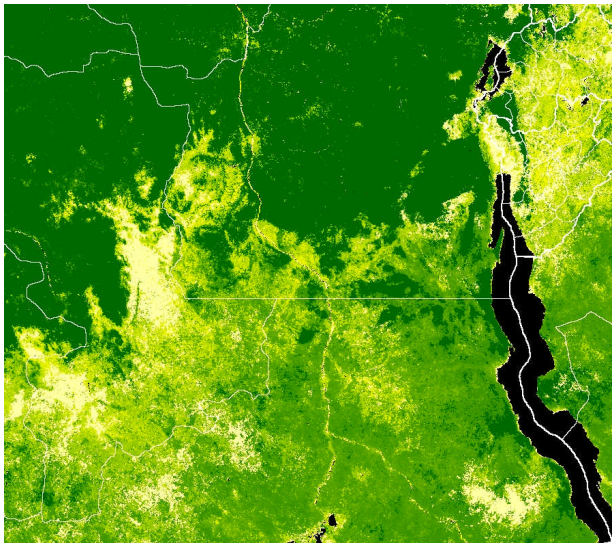


red=maximum annual ndvi
cyan=minimum annual red reflectance



average surface temperature of the four warmest months

350 km

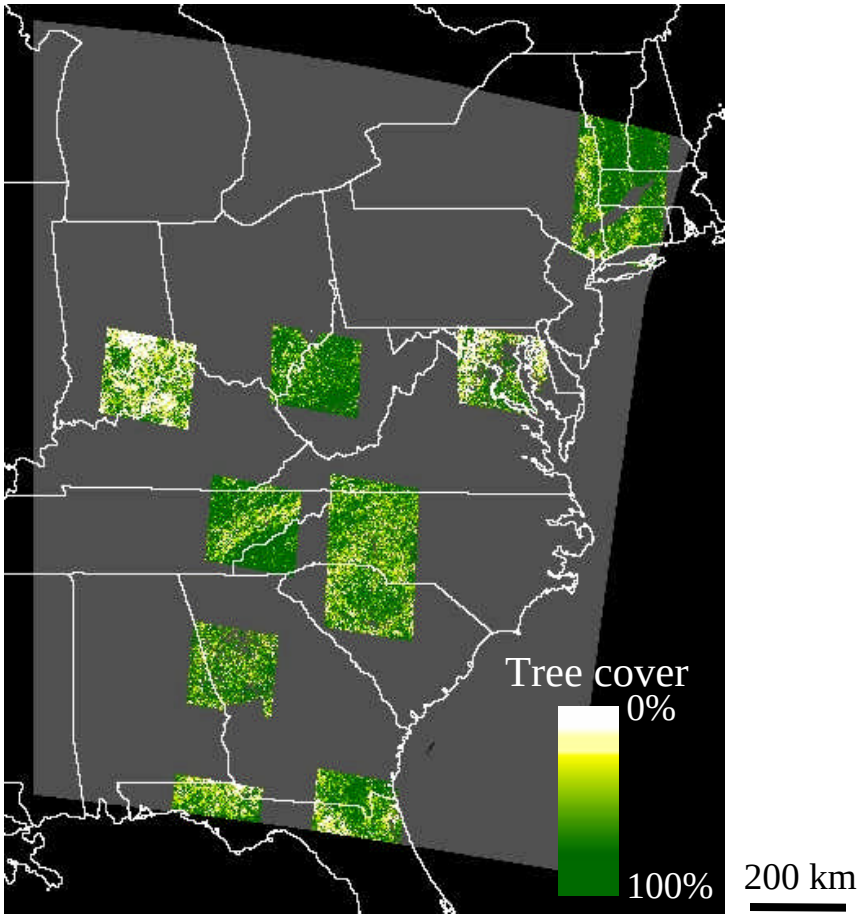


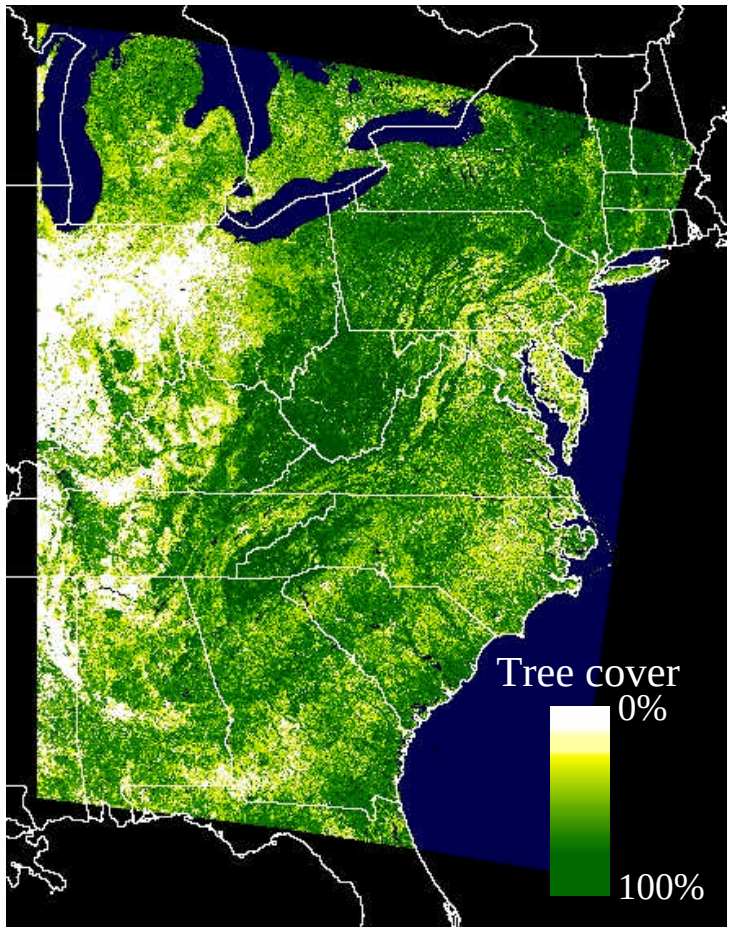
percent tree cover map

0%

100%

Training data and tree cover product

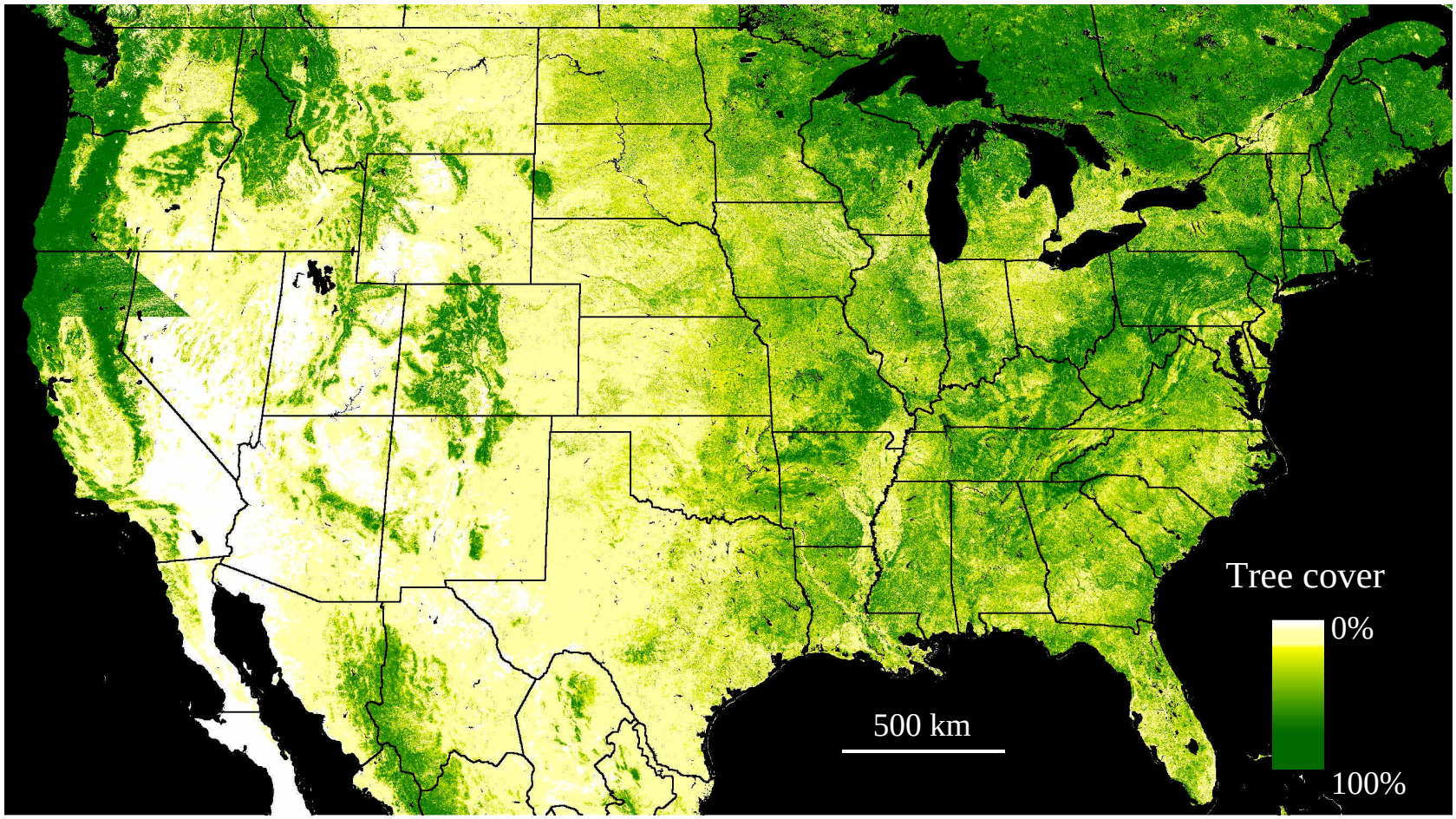




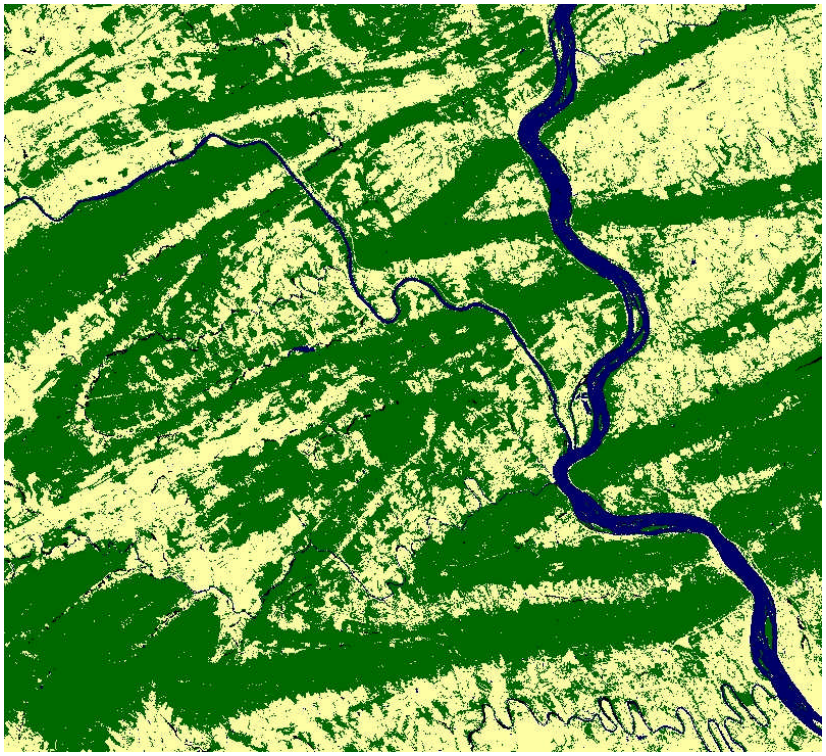
200 km

250 meter tree cover training data
from high-resolution classified images

Algorithm output

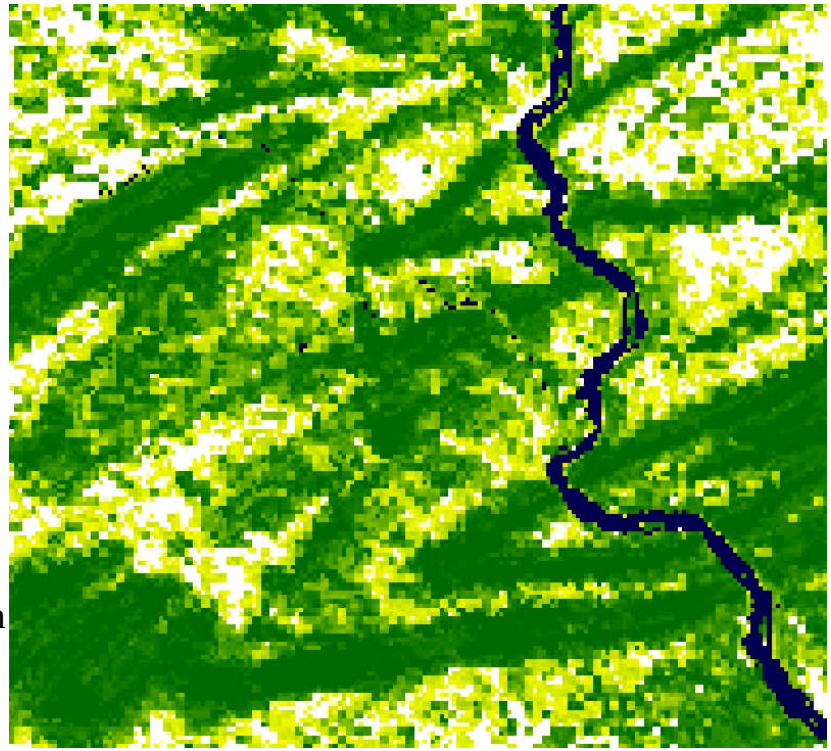


Percent tree cover map of the U. S. from 250 meter MODIS data using maximum NDVI composite for summer 2000 acquisitions



EPA Region 3 MRLC 30 meter map,
green is forest, beige non-forest

2.5km



MODIS 250 meter map

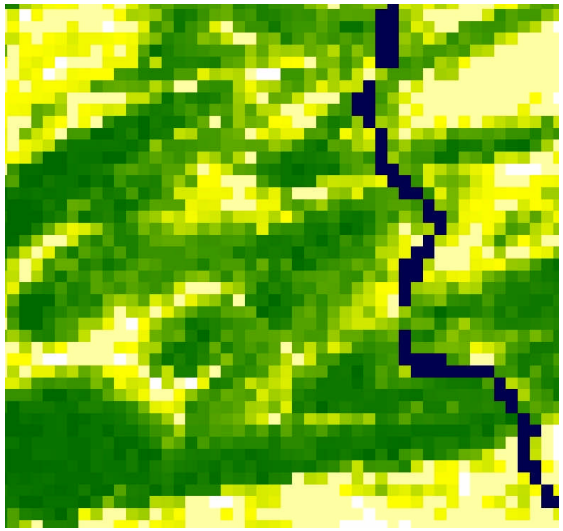
Tree cover

0%

100%

AVHRR 1km, 1995-96

10km



Validation of tree cover

- Use field measurements with high and very high resolution data (IKONOS) to scale up tree cover variable
- Compare scaled tree cover values at the MODIS resolution
- Sites for continental United States and Zambia

Vegetation Cover Conversion

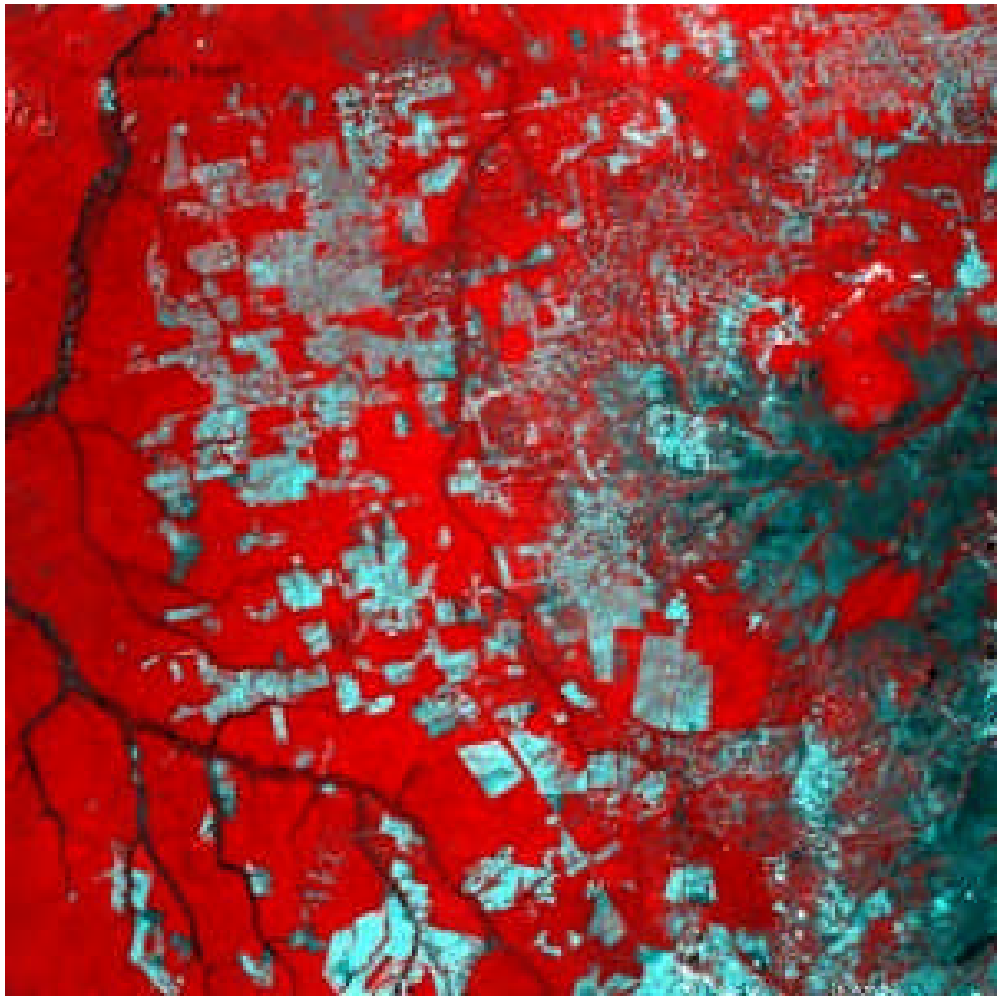
Flags that key land cover conversions have occurred.

Types of Land Cover Change of Concern for the VCC product

To / *From*	Forest	Non-Forest	Bare	Water	Burn Scar
Forest	-	**Deforest.**	**Deforest.**	**Flooding**	**Burn**
Non-Forest	**Regrowth**	-	**Urban.**	**Flooding**	**Burn**
Bare	**Regrowth**	**Agricul. Expansion**	-	**Flooding**	-
Water	**Flood retreat**	**Flood retreat**	**Flood retreat**	-	-
Burn	**Regrowth**	**Regrowth**	-	-	-

Central Brazil Along the Xingu River

- MODIS bands 1 (red) and 2 (near IR).
- Band 2 assigned to red and band 1 assigned to green and blue.
- 250m resolution.
- Data derived from L1B granule acquired on October 19, 2000

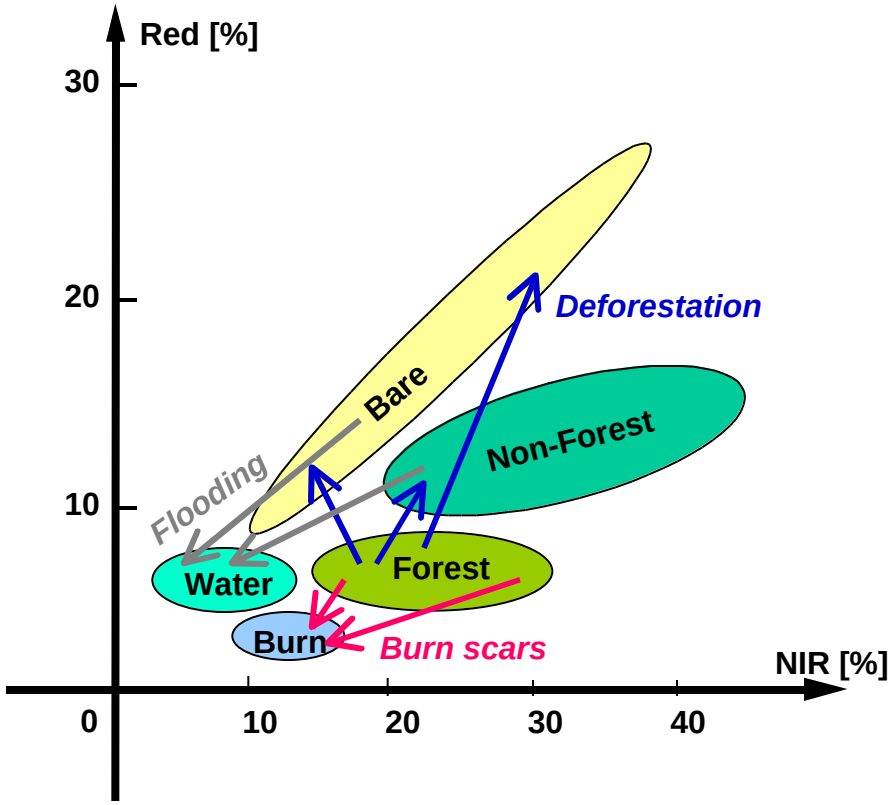


Change Detection Algorithms for the VCC Product

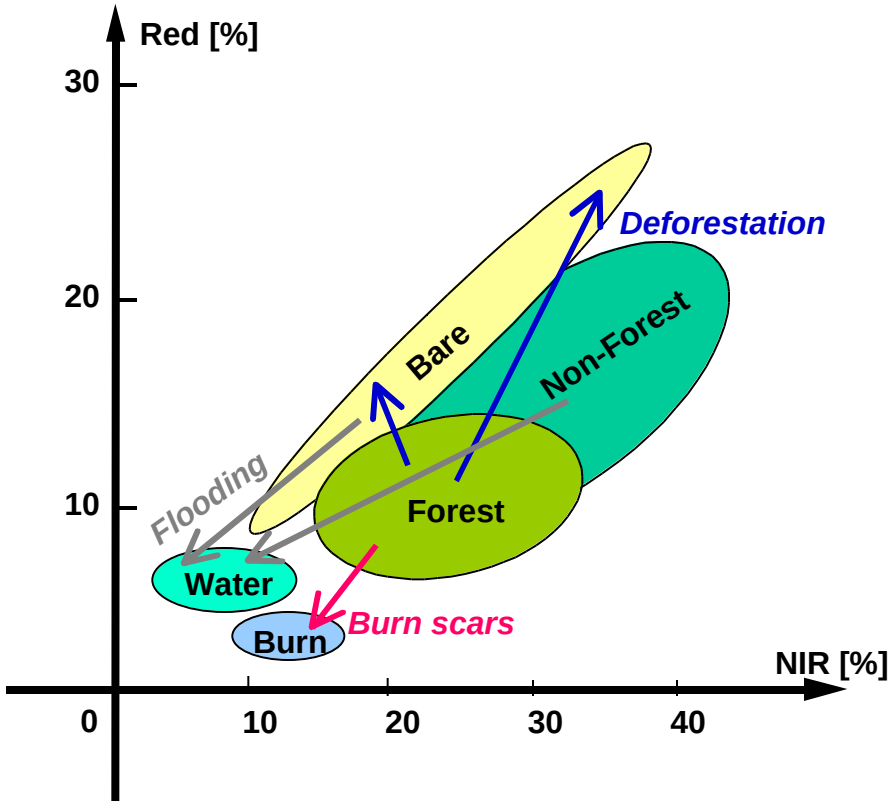
- **Multiple methods used for increasing confidence:**
  1. ***Red-NIR space partitioning;***
  2. ***Red-NIR space change vector characterization;***
  3. ***Modified-delta space thresholding;***
  4. ***Texture change detection;***
  5. ***Linear feature change detection.***
- **These methods are implemented with LUTs created for for each of 4 global regions and each of the 12 months.**
- **Results for all five methods are integrated and labeled.**

Visual Depiction of LUTs for Change Vector Characterization

Individual LUT for Each Month for Four Latitudinal Zones



Example for a growing season month



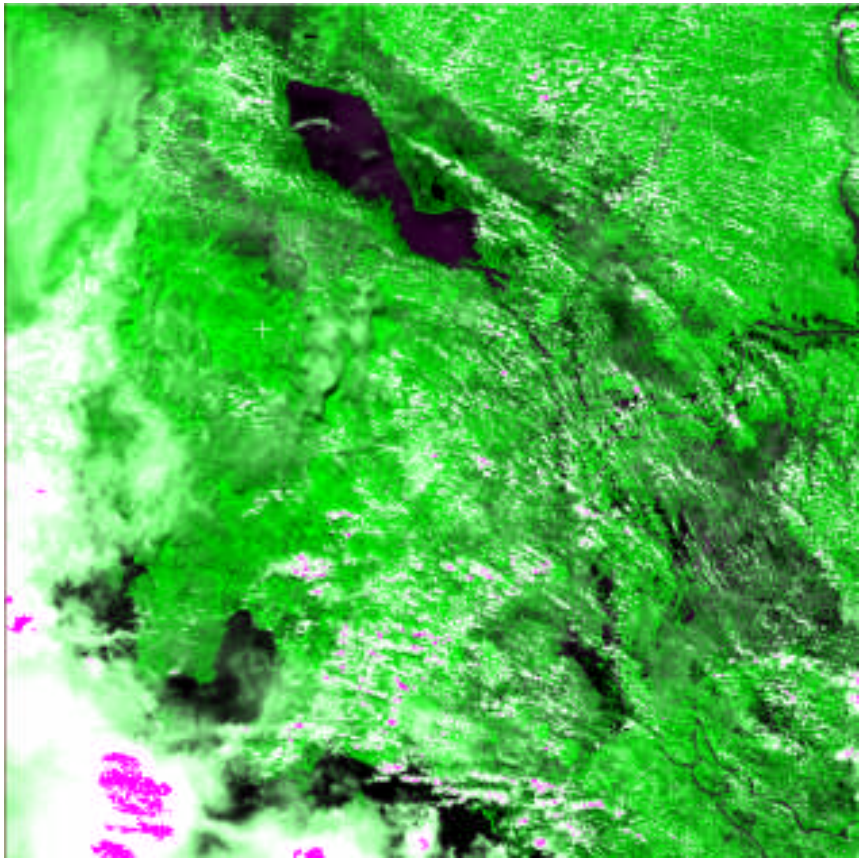
Example for a senescent month

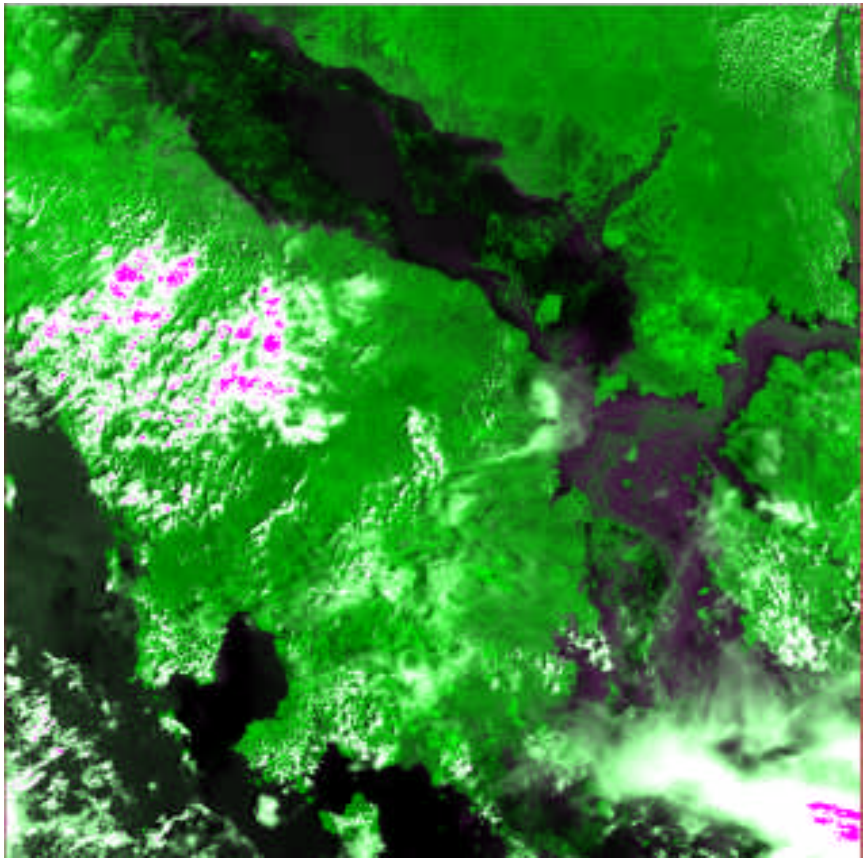
VCC Algorithm Refinement

- At-launch version of VCC utilizes Look-Up Tables generated from AVHRR heritage instrument;
  - These LUTs are being revised using MODIS retrievals.
- Changes in calibration and electronics gain present a challenge for algorithms such as VCC which utilize a time series.
- Compositing techniques for MOD44C require further refinement.
- Errors in upstream flags, such as those for clouds, require that the VCC algorithm be revised to include our own tests for quality conditions.

Floods in Cambodia from MODIS Level 1B 250m Data

Boeng Tonle Sab



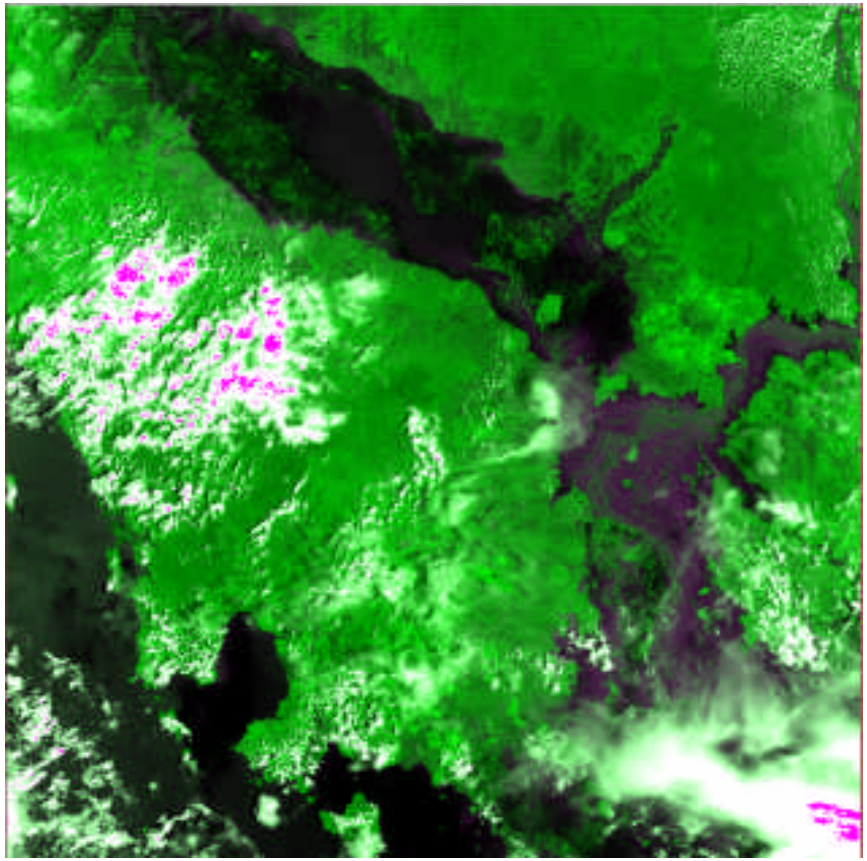


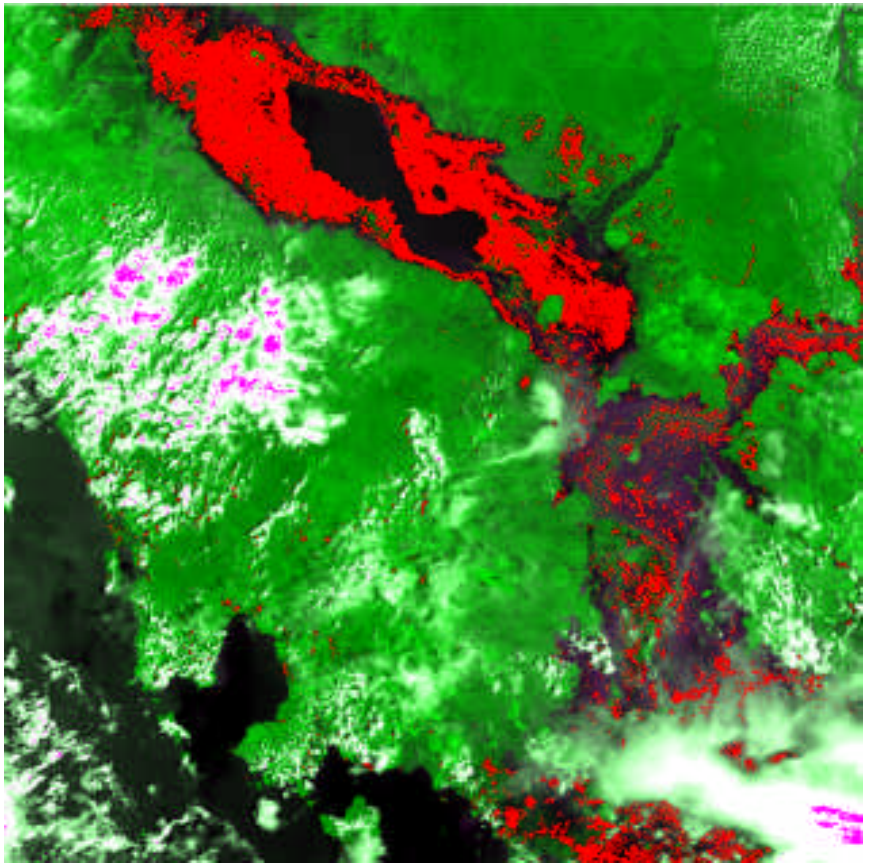
Day 183, 2000

50km

Day 259, 2000

Flood Areas Identified by VCC Change Vector Method Using MODIS Level 1B 250m Data

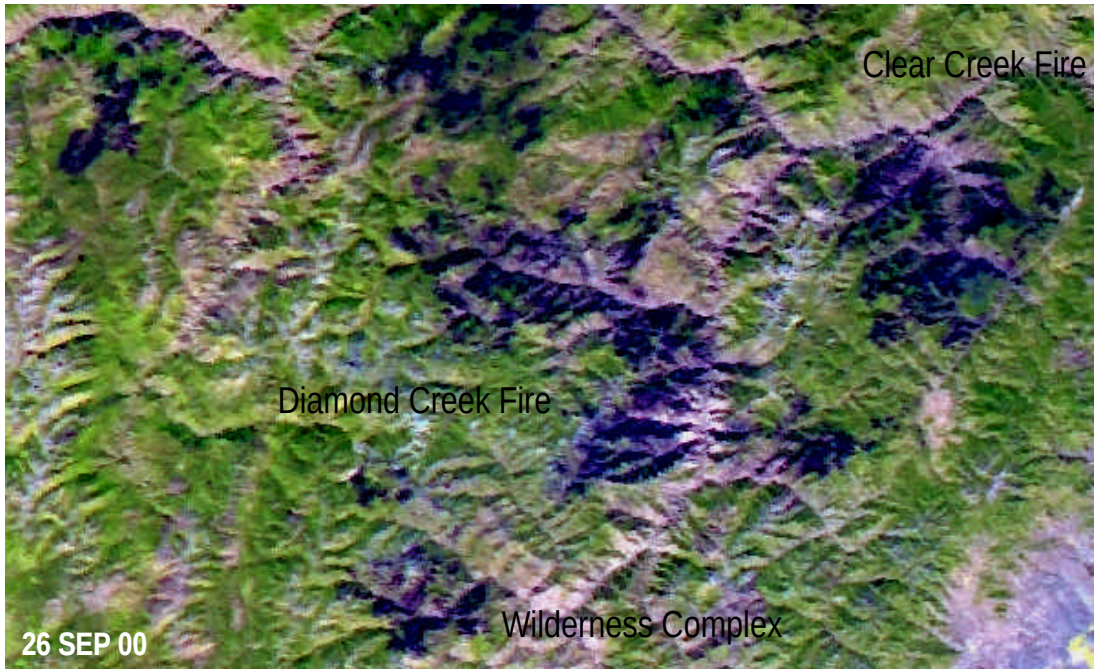




Day 259, 2000

50km

Flood Area Labeled in Red

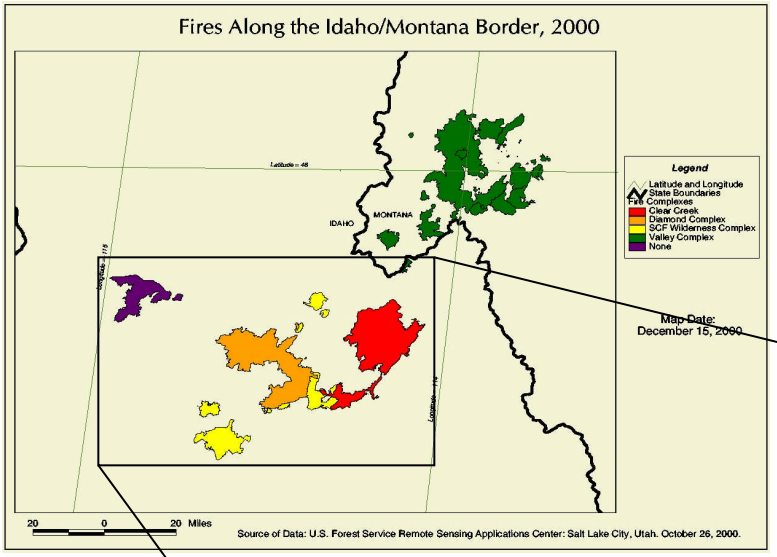


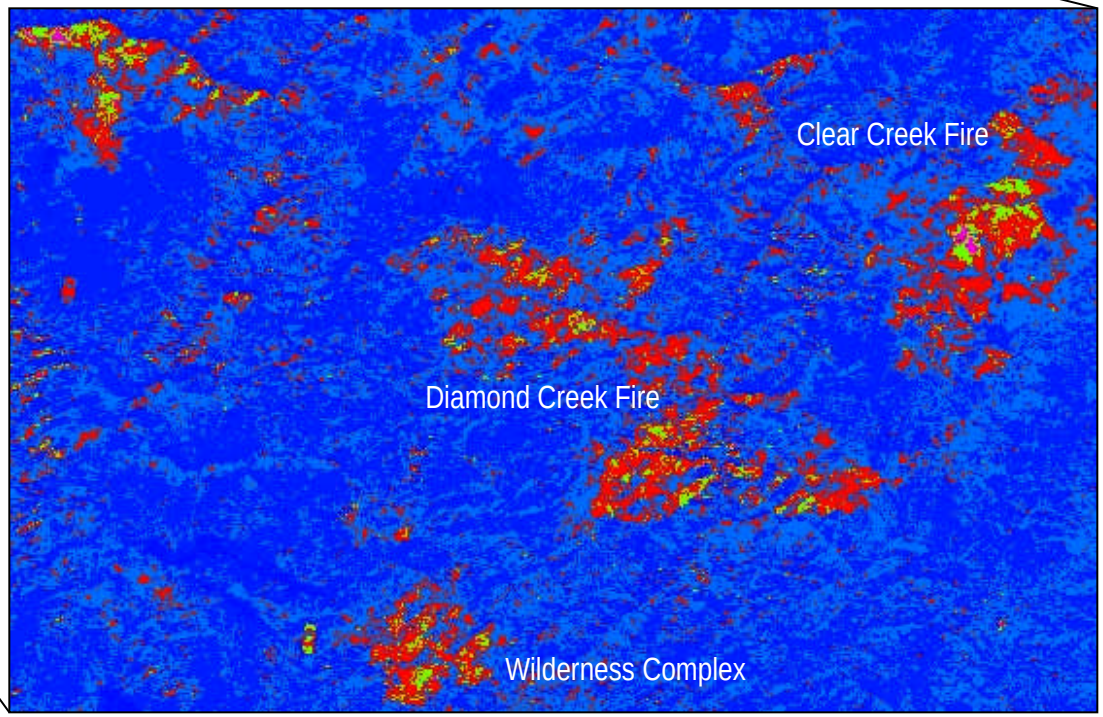
MODIS image of the Wilderness Complex and Diamond Creek Fire before and after event. Note that the Clear Creek Fire was in its early stages.

Visualization uses bands 5,2,1 assigned to red, green and blue.

The three white areas in the July image are data missing from the L1B granule.

VCC Change Vector Result with AVHRR Derived LUTs

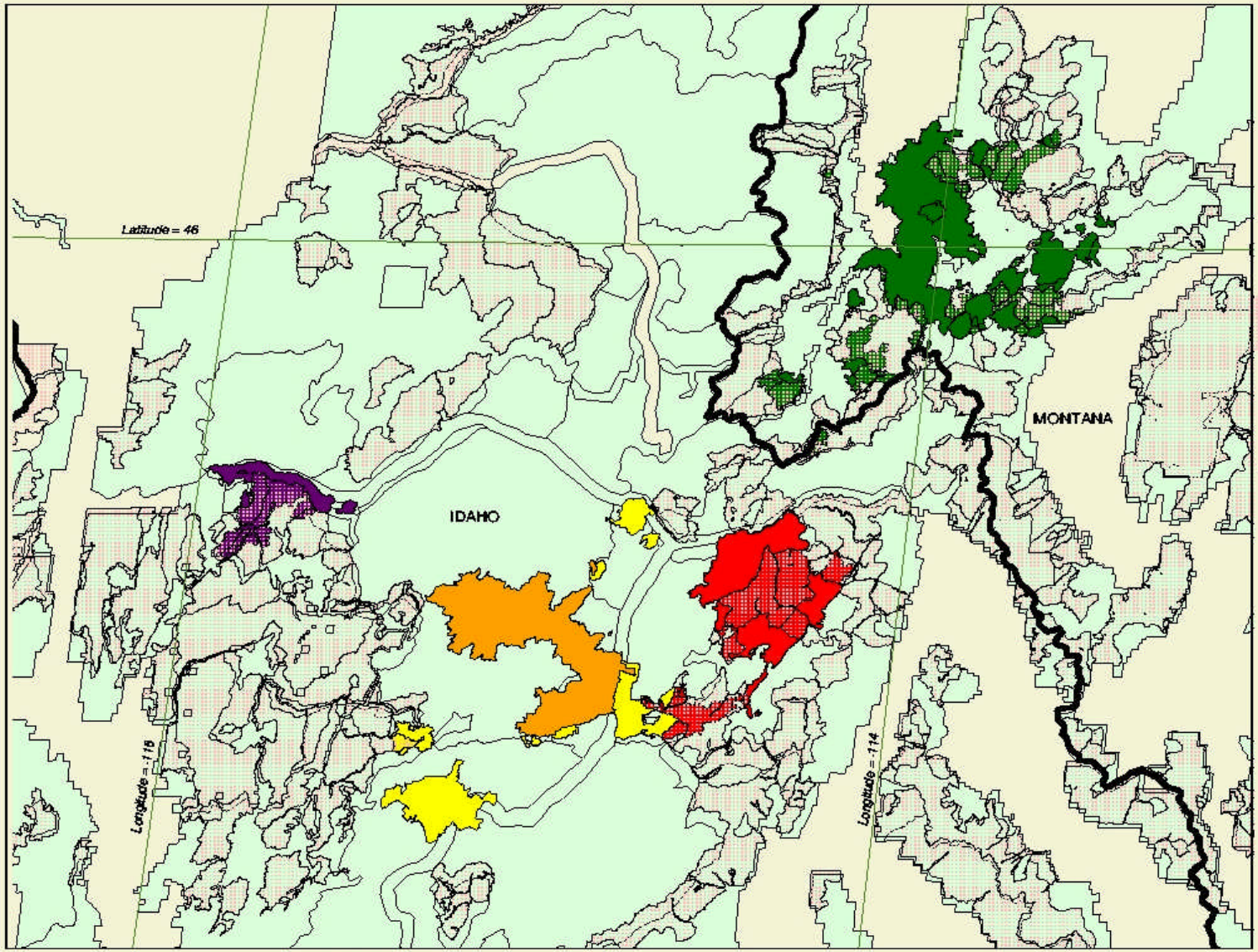




Likelihood of Change

low med high

Fires Along the Idaho/Montana Border, 2000



Legend

- Latitude and Longitude
- State Boundaries
- Inventoried Roadless Areas

Fire Complexes

- Clear Creek
- Diamond Complex
- SCF Wilderness Complex
- Valley Complex
- None
- Forest Area

Map Date:
December 15, 2000

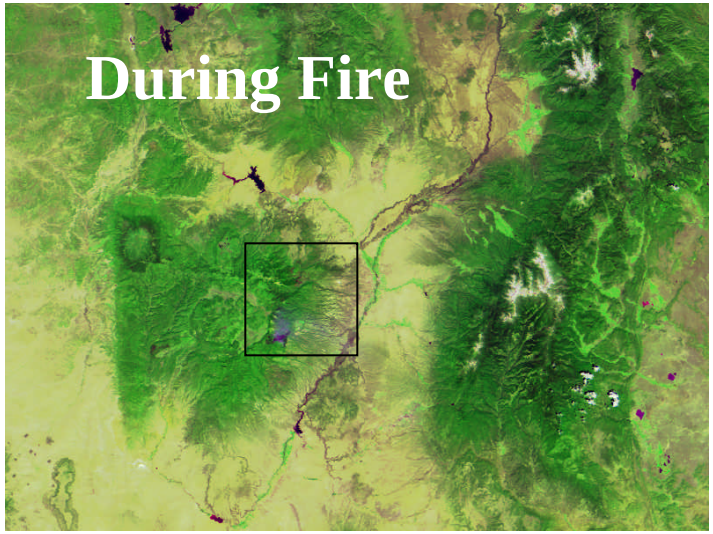
Roadless Areas make up 23.37% of the total Forested Area

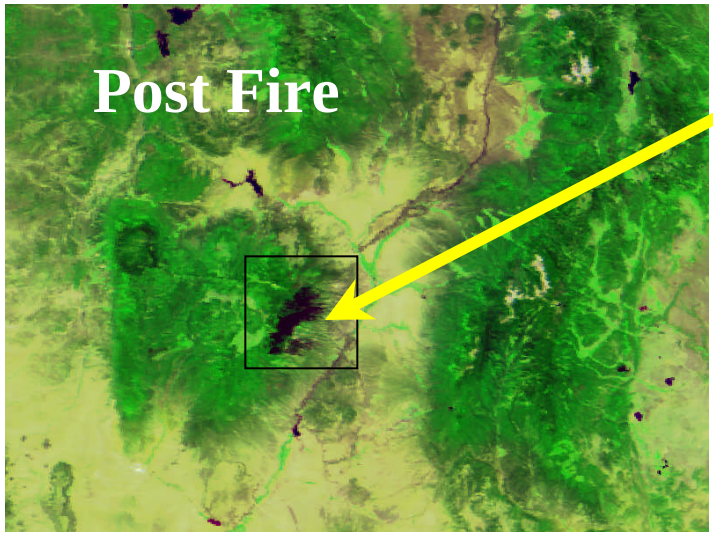
Of all of the fires in the area, 27.89% were in Roadless Areas

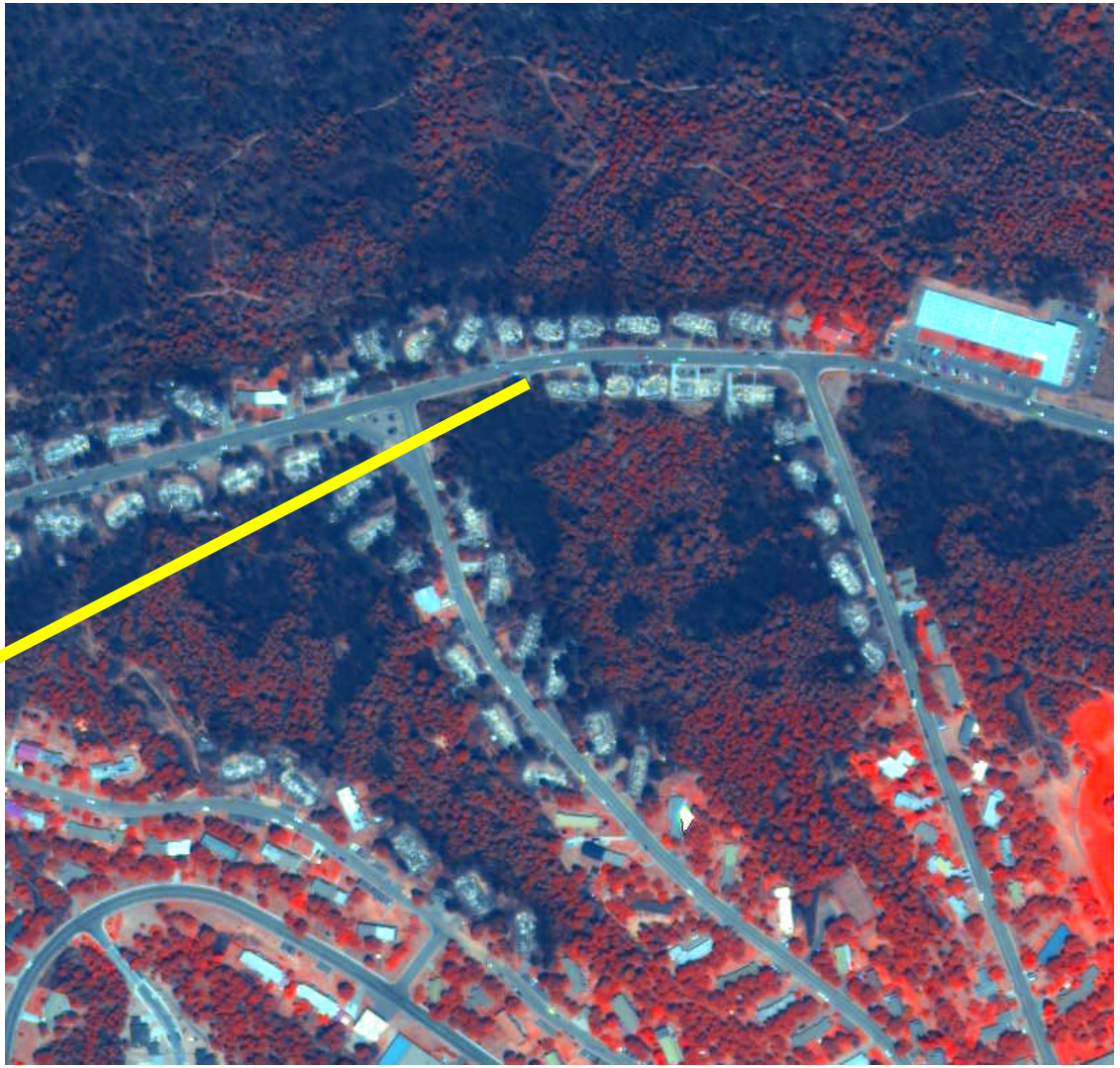
20 0 20 Miles

Source of Data: U.S. Forest Service Remote Sensing Applications Center: Salt Lake City, Utah. October 26, 2000.

Cerro Grande (Los Alamos) Fire



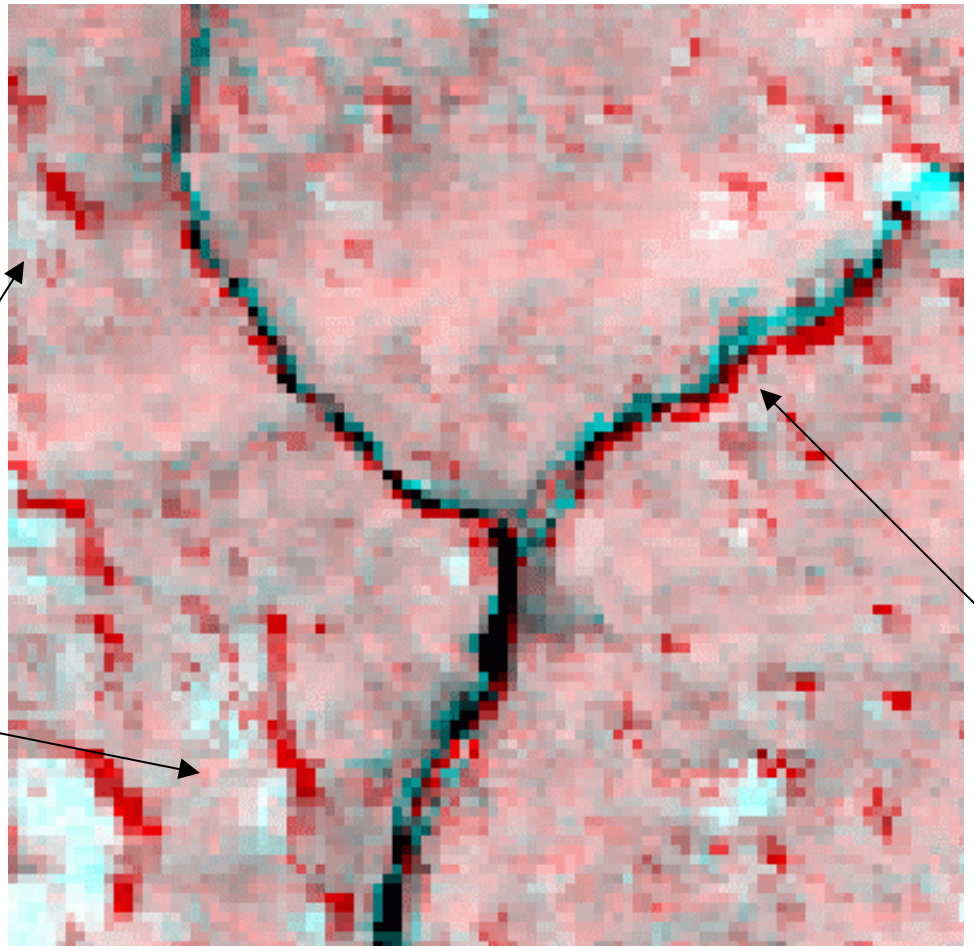




MODIS 250m

IKONOS 1m pan, 4m multi-spectral

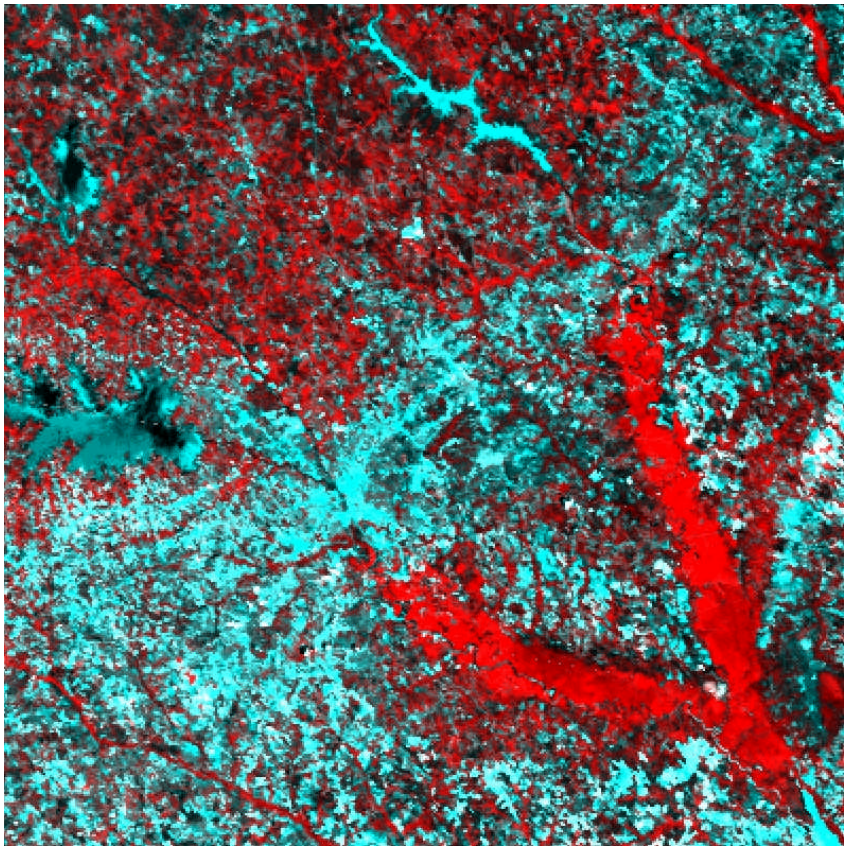
Concerns regarding day-to-day registration of L2G data.

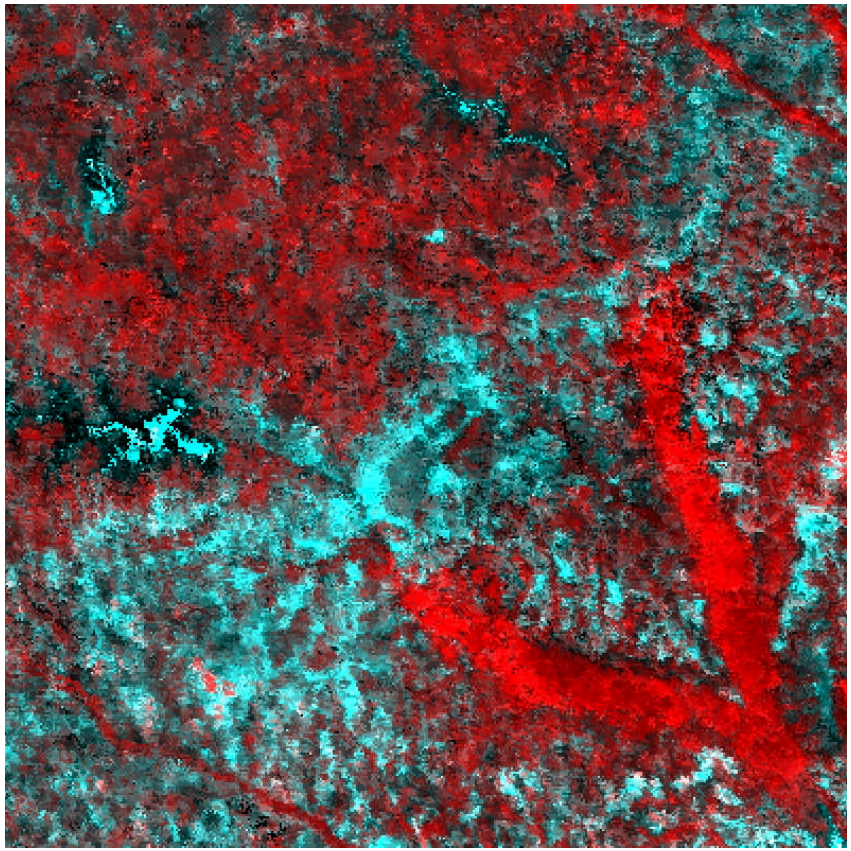


Example shows overlay of L2G 250m band 2 for Day 162 (near nadir) and 174 (off nadir) at the confluence of two rivers in Pennsylvania. The first day is assigned to red and the second day is assigned to green and blue. Dark red and cyan show geolocational variation between the two images

Degradation of information content from compositing

example from Columbia, South Carolina





25 km

250 meter infrared and red image of level 1b data from June 10, 2000

250 meter infrared and red image of NDVI composite from available Summer level 2g data

Product Distribution

- Initial VCC results will be released March 30, 2001 from *http://glcf.umiacs.umd.edu*
- Recurring VCC production will be distributed from the EDC-DAAC.
- GLCF currently distributing 16-day VI composite product for the conterminuous U.S.
  - Albers projection with standard USGS parameters.
- State sub-sets became available in January.
- GLCF also distributing 250m and 500m data sets derived from L1B for areas of interest to land cover community.
  - Format is flat binary and projection is sinusoidal with a local meridian.

Fire and Burned Area

Chris Justice [1], Louis Giglio [2], Jacques Descloitres [2], David Roy [1], Stefania Korontzi [1], Samuel Alleaume [3], Yoram Kaufman [4]

[1]University of Maryland
[2] Science Systems and Applications, Inc.
[3] University of Virginia
[4] NASA Goddard Space Flight Center

Science Rationale for the MODIS Fire Products

- **Fire is an important source of trace gas and particulate emissions**
- **Fire is a proximate cause / indicator of land cover change**
- **Fire is an important biogeochemical process with a major role in the carbon and nitrogen cycles**
- **Fire is an important ecological disturbance regime**
- **Fire frequency can be expected to change with climate change and variability**
- **Fire is a major land management practice in tropical systems**
- **Fire frequency will change with population dynamics**
- **Fire can be a natural hazard with large societal costs and impacts**

MODIS Fire Bands

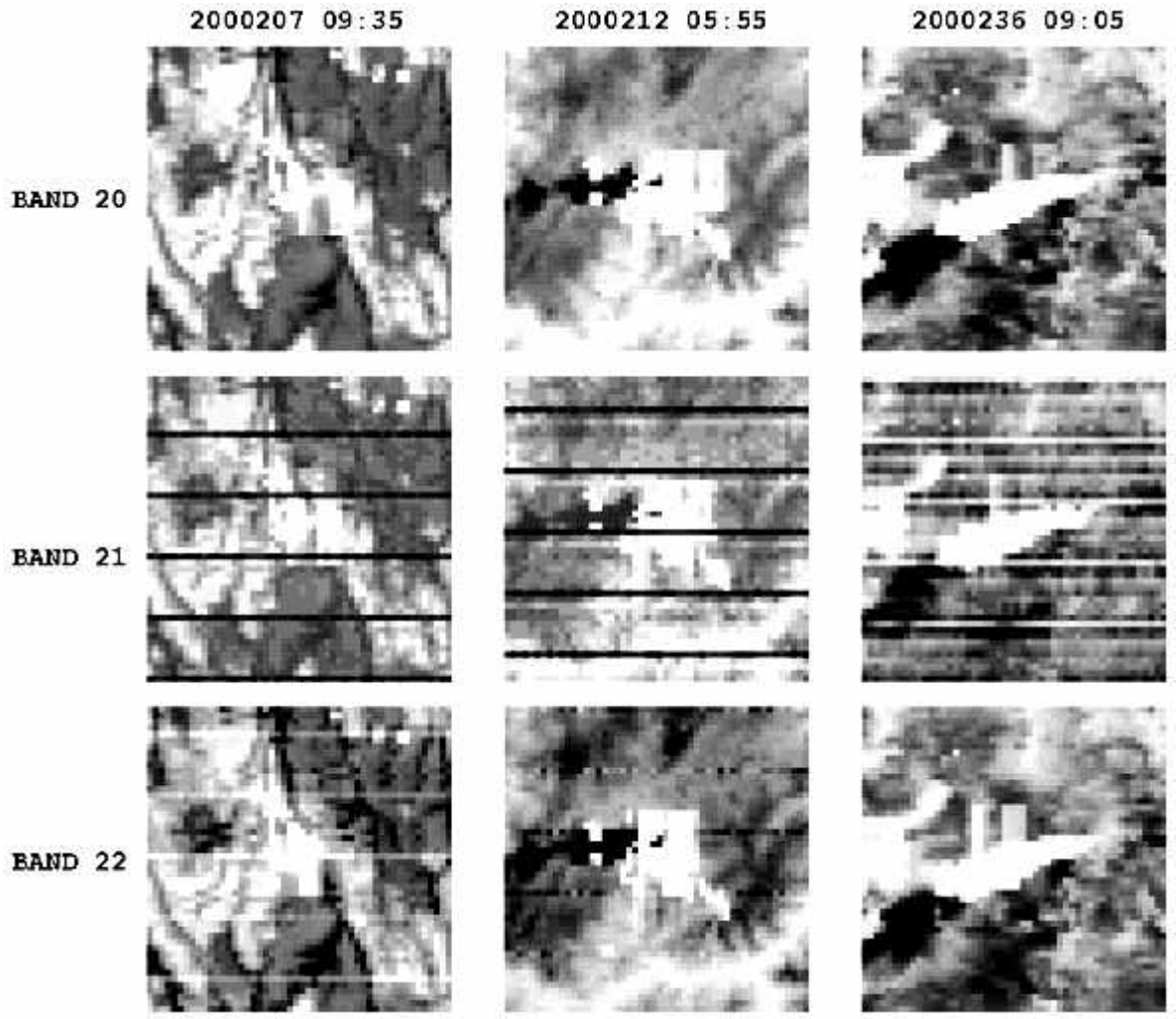
- **1 km fire bands**
  - Channel 21: 3.96 µm, ~ 450 K saturation
  - Channel 31: 11.0 µm, ~ 400 K saturation
  - Channel 22: 3.96 µm, ~ 330 K saturation - lower noise, lower quantization error, 1 km multi-purpose band
- **Status (Pre-November 2000)**
  - Channel 21
    - **Dead detector #9**
    - **More noise than expected**
    - **Not yet completely calibrated**
    - **Mirror side effect visible -- little or no impact on fire product**
    - **Artifacts sometimes significant in high-contrast scenes**
  - Channel 22
    - **Dead detector #4**
    - **Noisy detectors #7,8**
    - **Artifacts sometimes significant in high-contrast scenes**
  - Channel 31
    - **Some striping -- currently no impact seen on fire detection**

Instrument Performance

Impact of Instrument Problems on Fire Detection (Pre-Nov. 1)

- Degraded ability to detect small/cool fires
  - 50+ % of scans affected
- Degraded ability to detect large/hot fires
  - ~10% of scans affected
- Striping in L2 fire product
  - Can propagate up through L3 products
- Unable to retrieve properties for ~ 10% of fire pixels
- Artifacts sometimes interfere with detection of large fires
- Artifact-induced false alarms (rare)

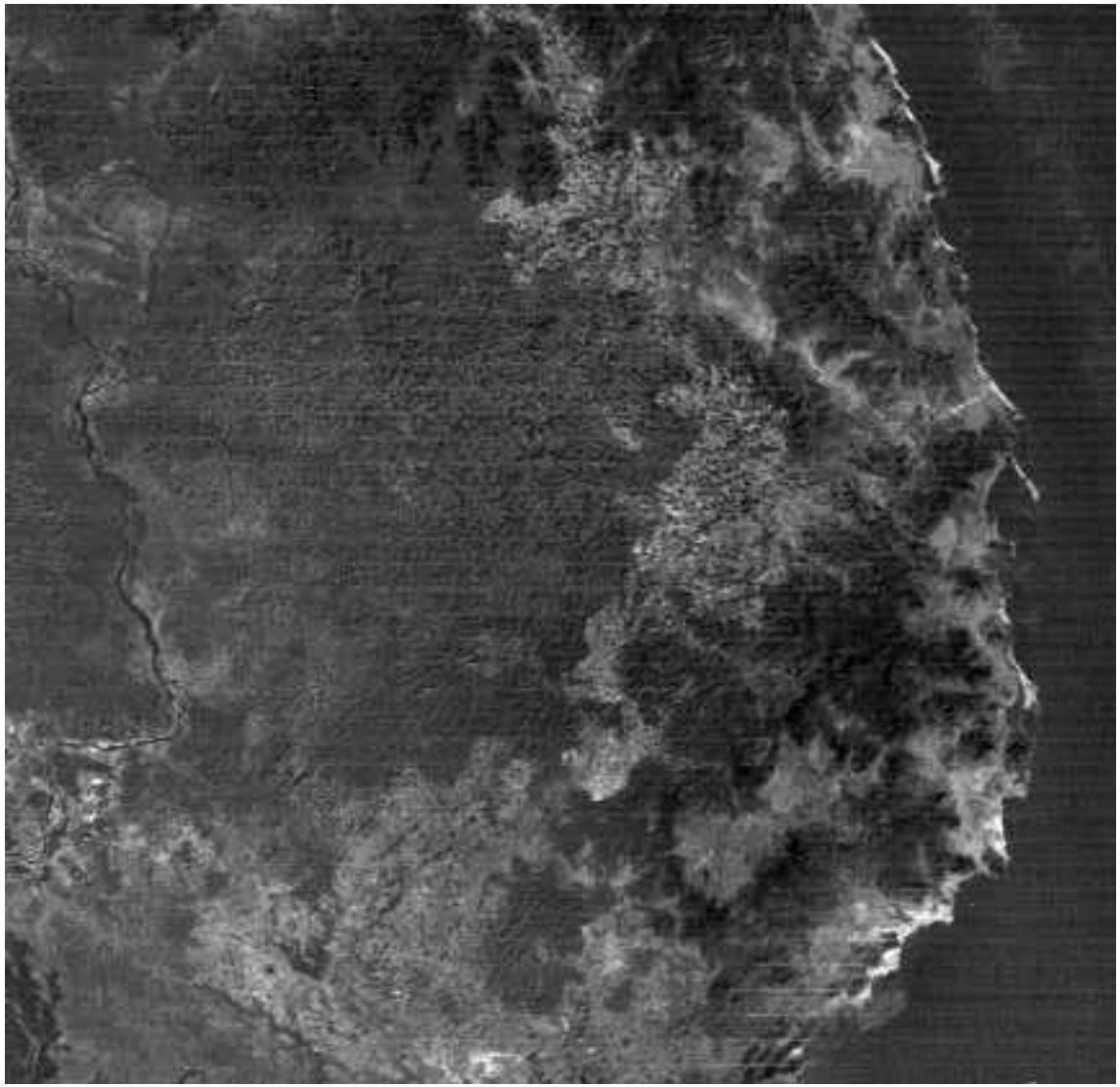
Mid-IR Artifacts (pre-Nov 1)



Current Status

- **Move to B-Side Electronics (Nov 1 2000)**
- **Status (Post-November)**
  - **Channel 21**
    - **All detectors functional**
    - **Slightly degraded (but still useful) detector #9**
    - **Artifacts sometimes significant in high-contrast scenes**
    - **Evaluation in progress**
  - **Channel 22**
    - **All detectors functional and well-calibrated**
    - **Artifacts sometimes significant in high-contrast scenes**
    - **Evaluation in progress**
  - **Channel 31**
    - **Evaluation in progress**
  - **Calibration on-going**
    - **needed for high gain channels**
    - **establish channel saturation levels**

Channel 21 after Nov. 1st



MODIS Active Fire Product

- MODIS Active Fire Algorithm
  - Absolute and Difference Thresholds for Bands 2, 21,22, and 31
  - Also uses:
    - Difference with background brightness temperatures (21/22/31)
    - Standard deviation of surrounding pixel brightness temperatures
    - Mod 35 - Cloud Mask
    - Geolocation
    - Bands 1 and 2 for glint rejection and QA flags

MODIS Fire Products

- **MODIS 8-Day Composite Fire Product MOD14A1** Chris Justice, Louis Giglio
  - Level 3A daily, gridded (1 km) composite of the most-confident fire pixel detected in each grid cell. For convenience, eight days of data are packaged into a single file.

- **MODIS 8-Day Summary Fire Product MOD14A2** Chris Justice, Louis Giglio
  - Level 3A gridded (1 km) composite of the most-confident fire pixel detected in each grid cell over an eight-day compositing period.

- ***MODIS Daily Level 2 Products (intermediate 3 month archive)*** Chris Justice, Louis Giglio
    - ***L2 orbit granules @ 1km***
    - ***L2G daily per tile @ 1km***

- **MODIS Global Daily Fire QA Product MOD14QA** Jacques Descloitres
  - Level 3A daily, coarse-resolution (5 km) global summary fire product indicating areas in which active fires were detected.

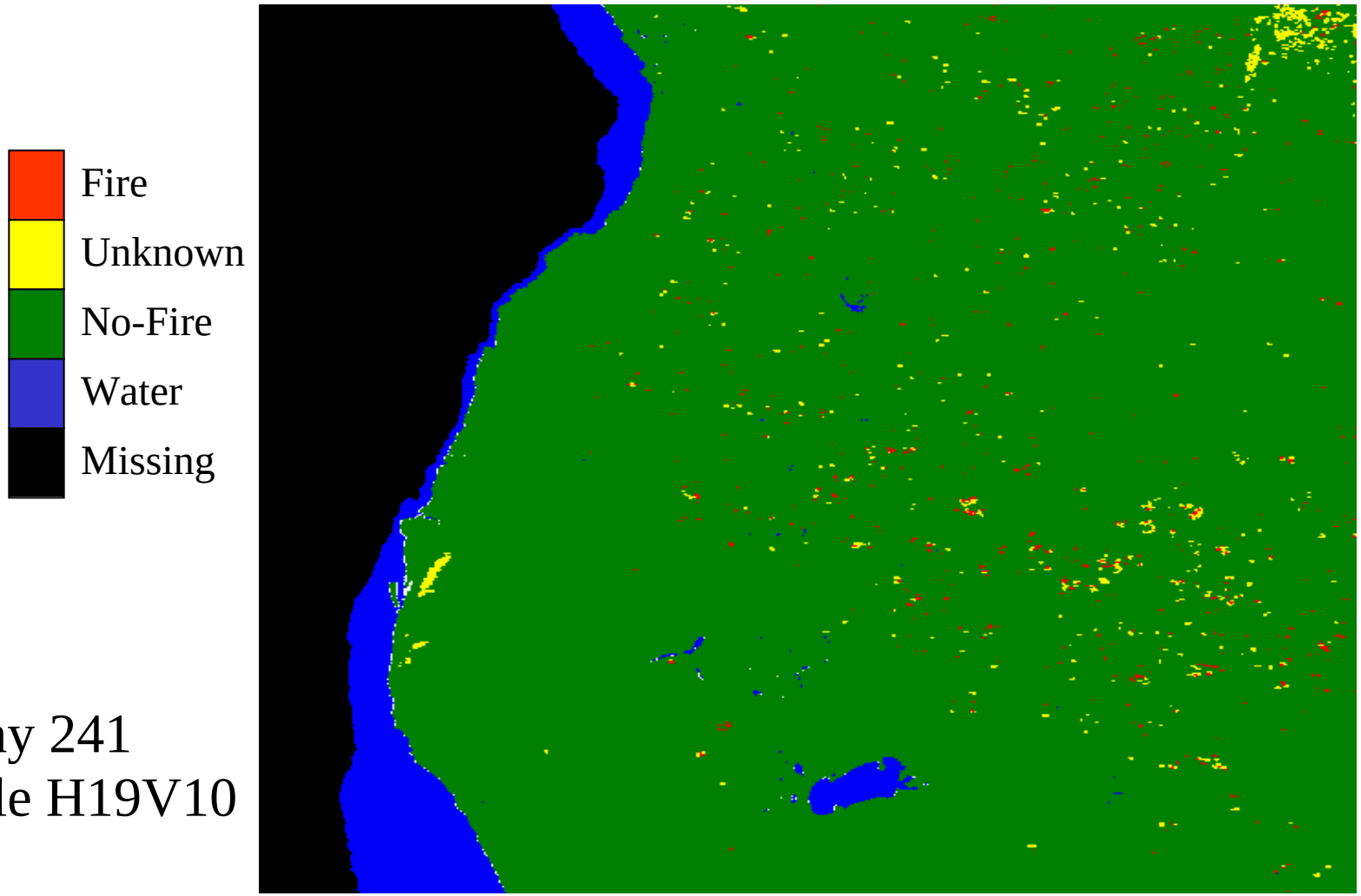
- ***MODIS 10 km Climate Modeling Product MOD14CMG1*** Yoram Kaufman
  - Level 3A monthly gridded statistical summary of consolidated fire pixels intended for use in regional and global modeling.

- ***MODIS 0.5 Degree Climate Modeling Product MOD14CMG2*** Yoram Kaufman
  - Level 3A monthly gridded statistical summary of consolidated fire pixels intended for use in regional and global modeling.

Currently Available MODIS Fire Products

- **Active-fire detection (location & timing)**
  - **Swath (L2)**
    - **Fire mask**
    - **QA plane**
    - **Table of detailed information about each fire pixel**
  - **L3 1-km gridded (daily and 8-day summaries)**
  - **L3 5-km daily global browse (for QA)**

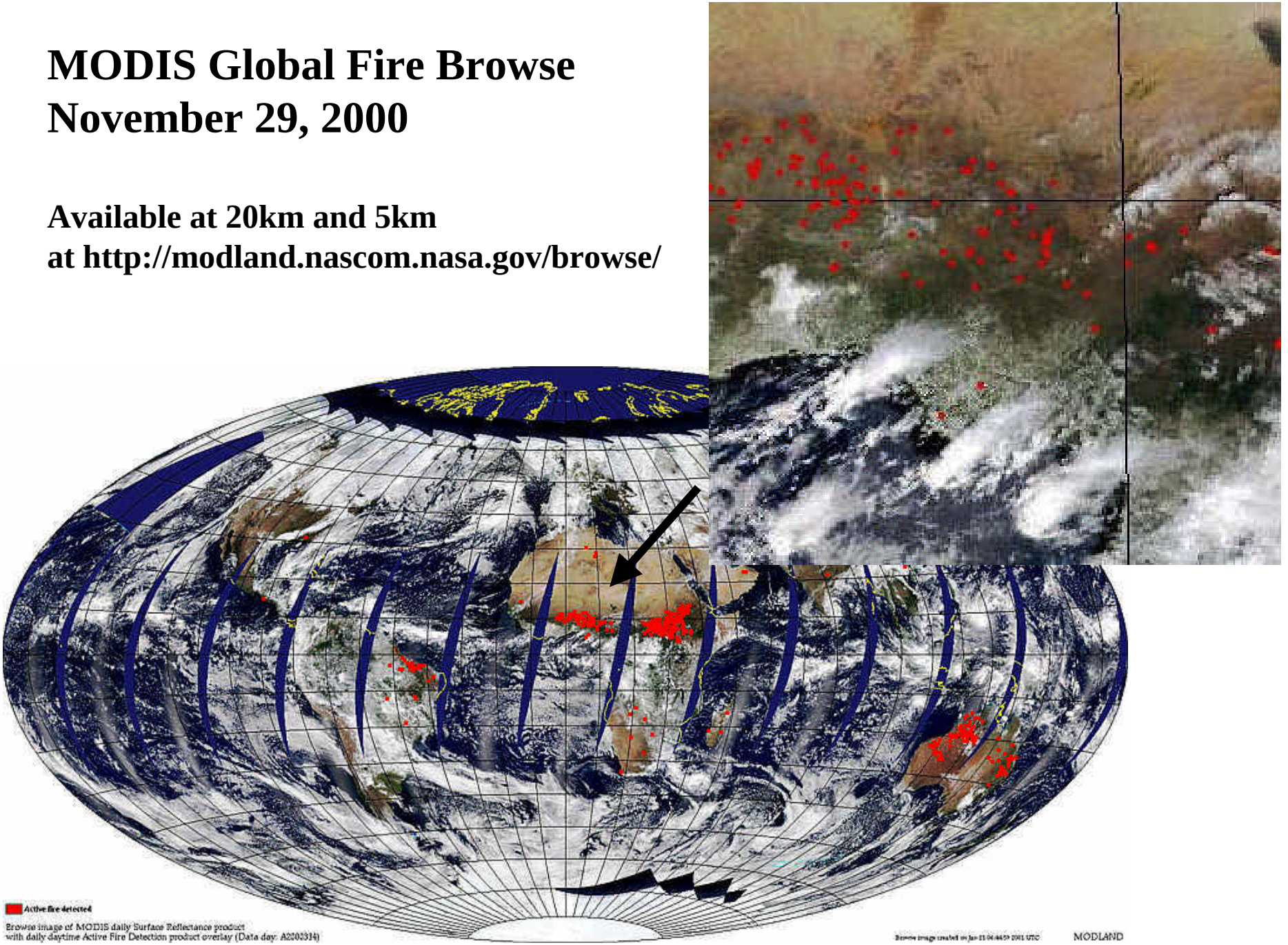
Example 8-day L3 Fire Product
Angola



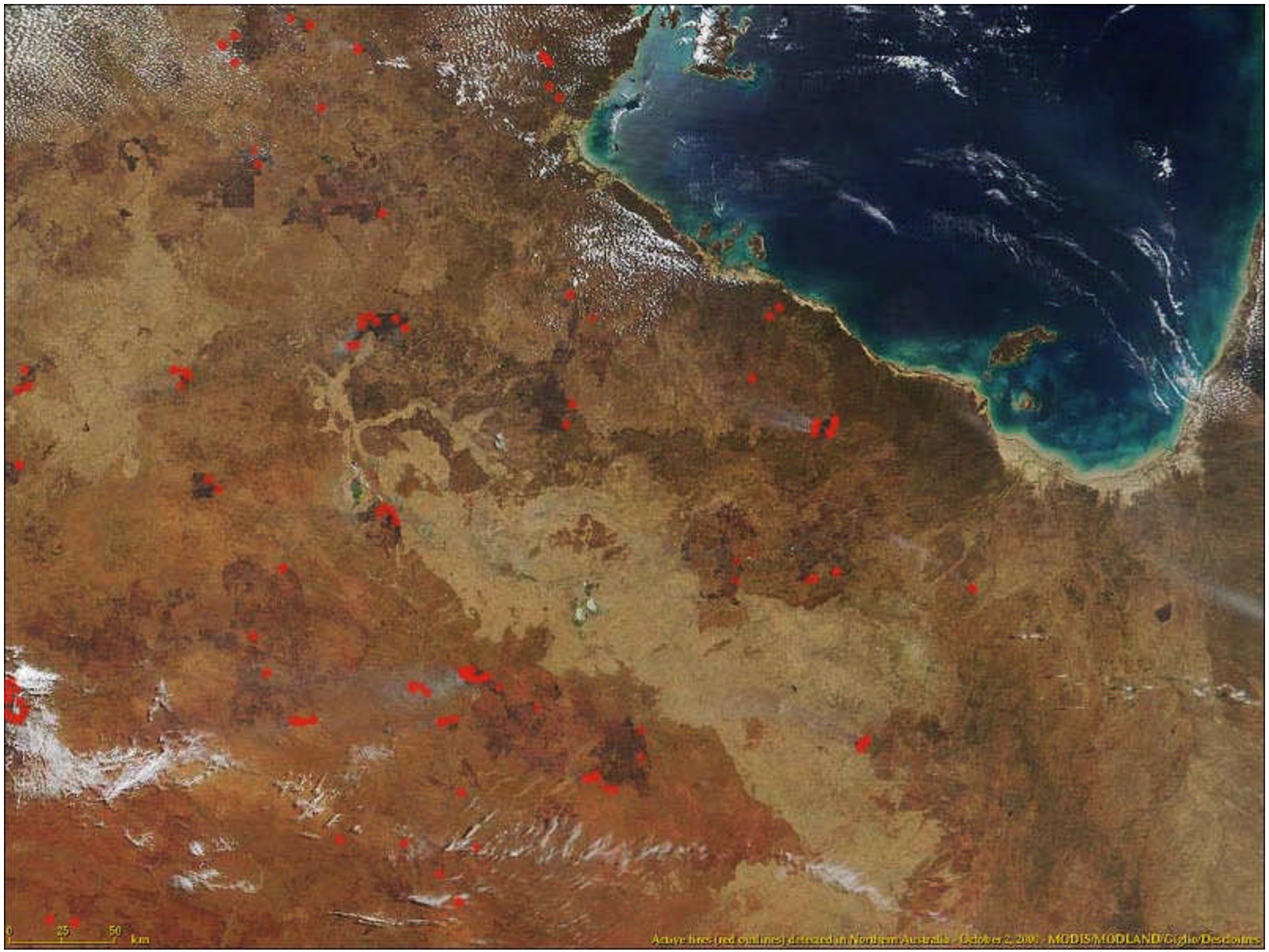
Day 241
Tile H19V10

MODIS Global Fire Browse
November 29, 2000

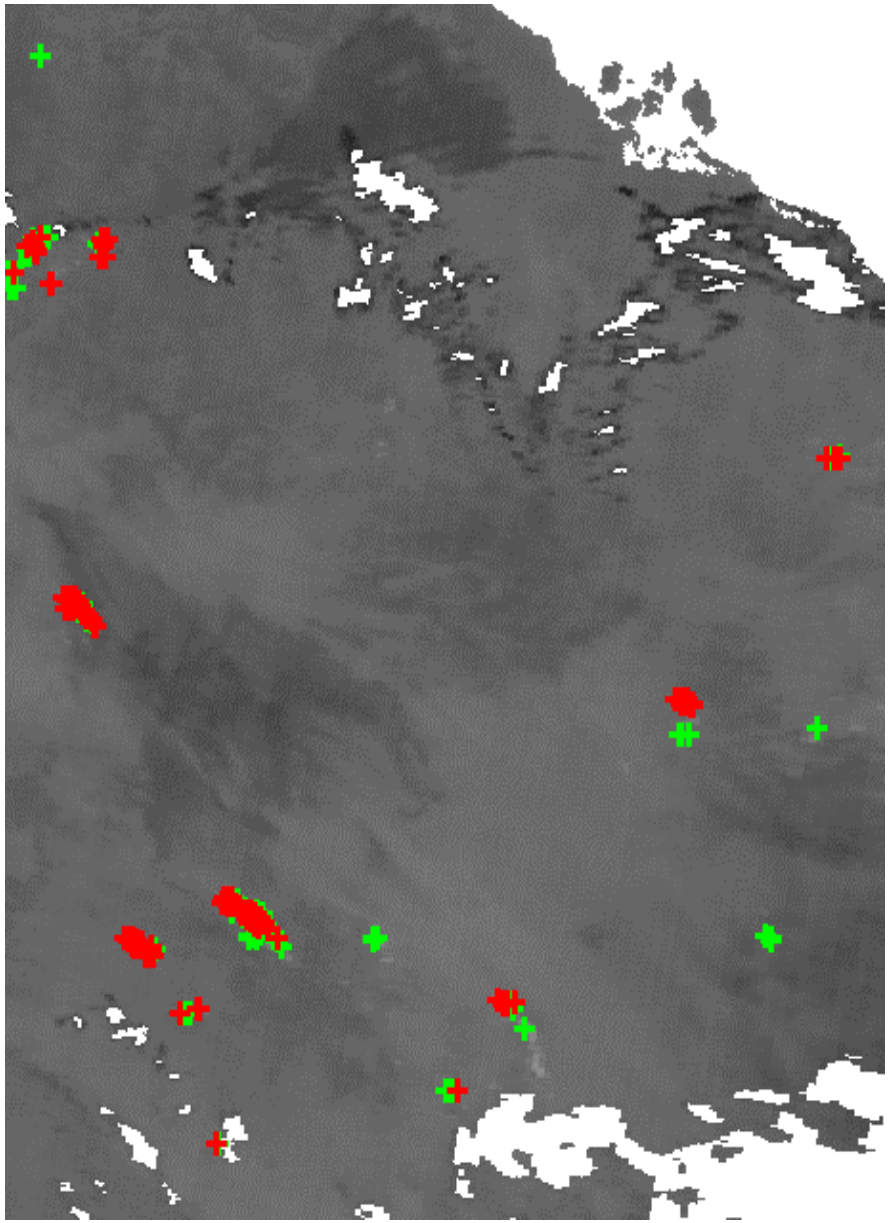
Available at 20km and 5km
at http://modland.nascom.nasa.gov/browse/



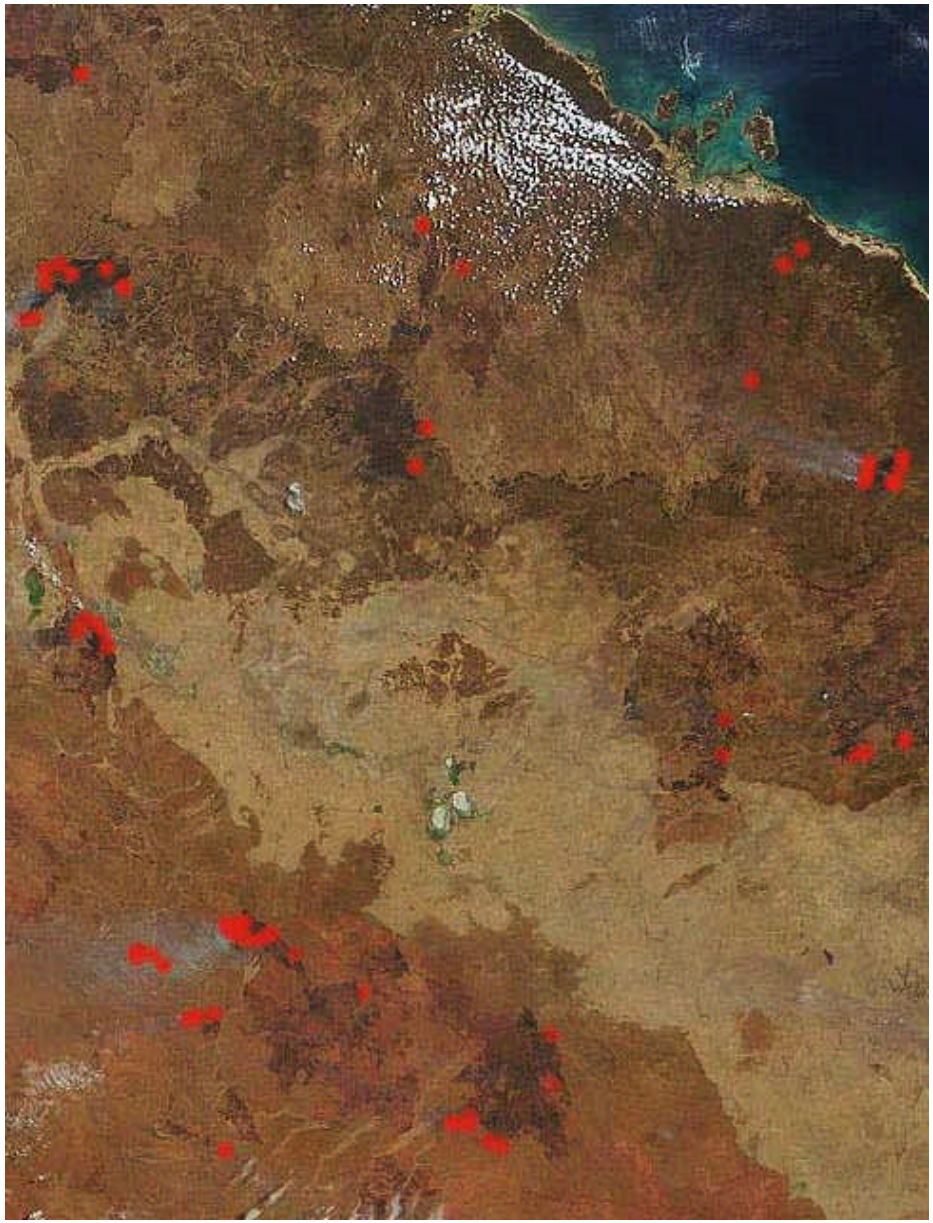
MODIS Fires, NW Australia, Oct 2, 2000



AVHRR (3.45am)

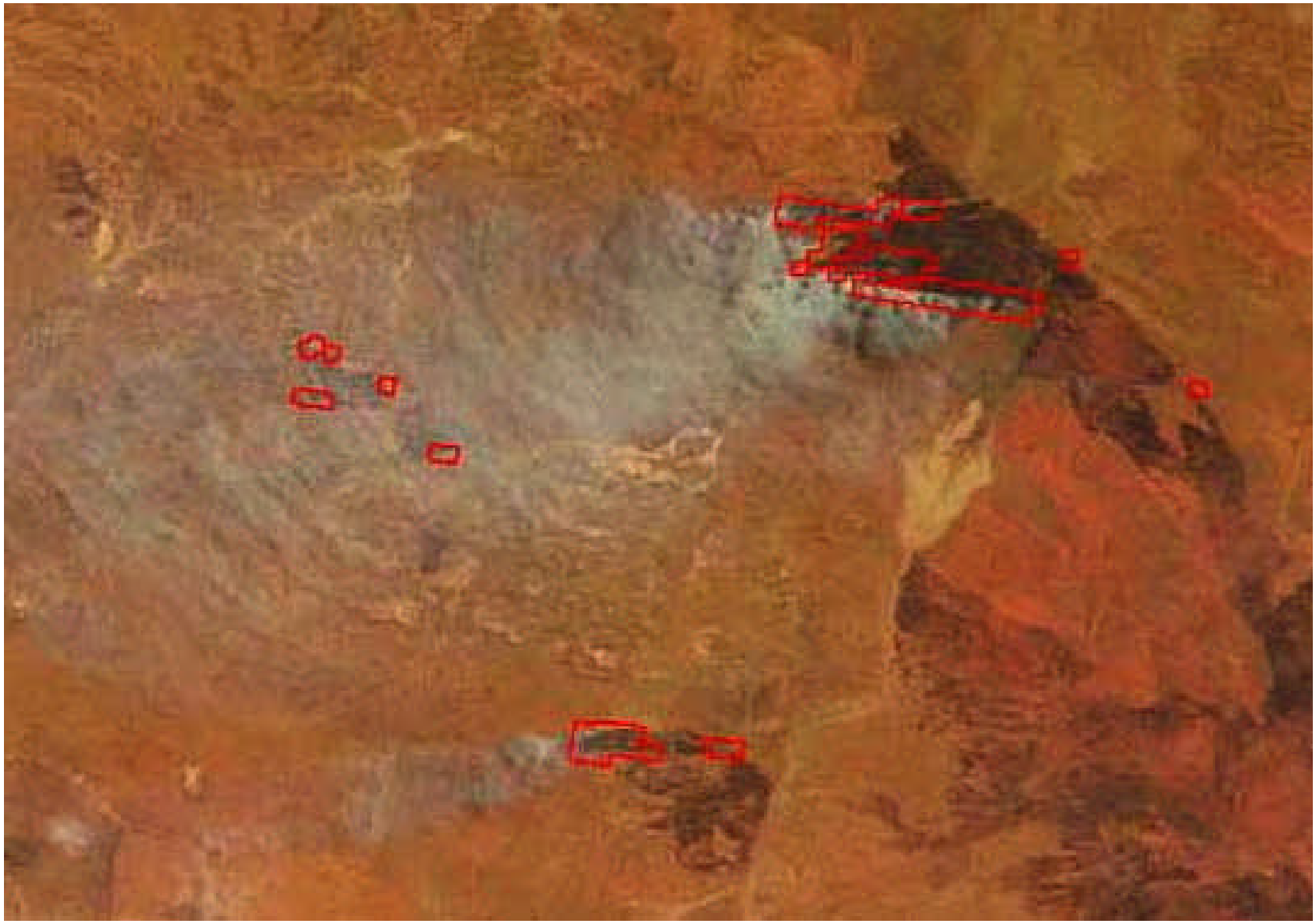


MODIS (10.30am)

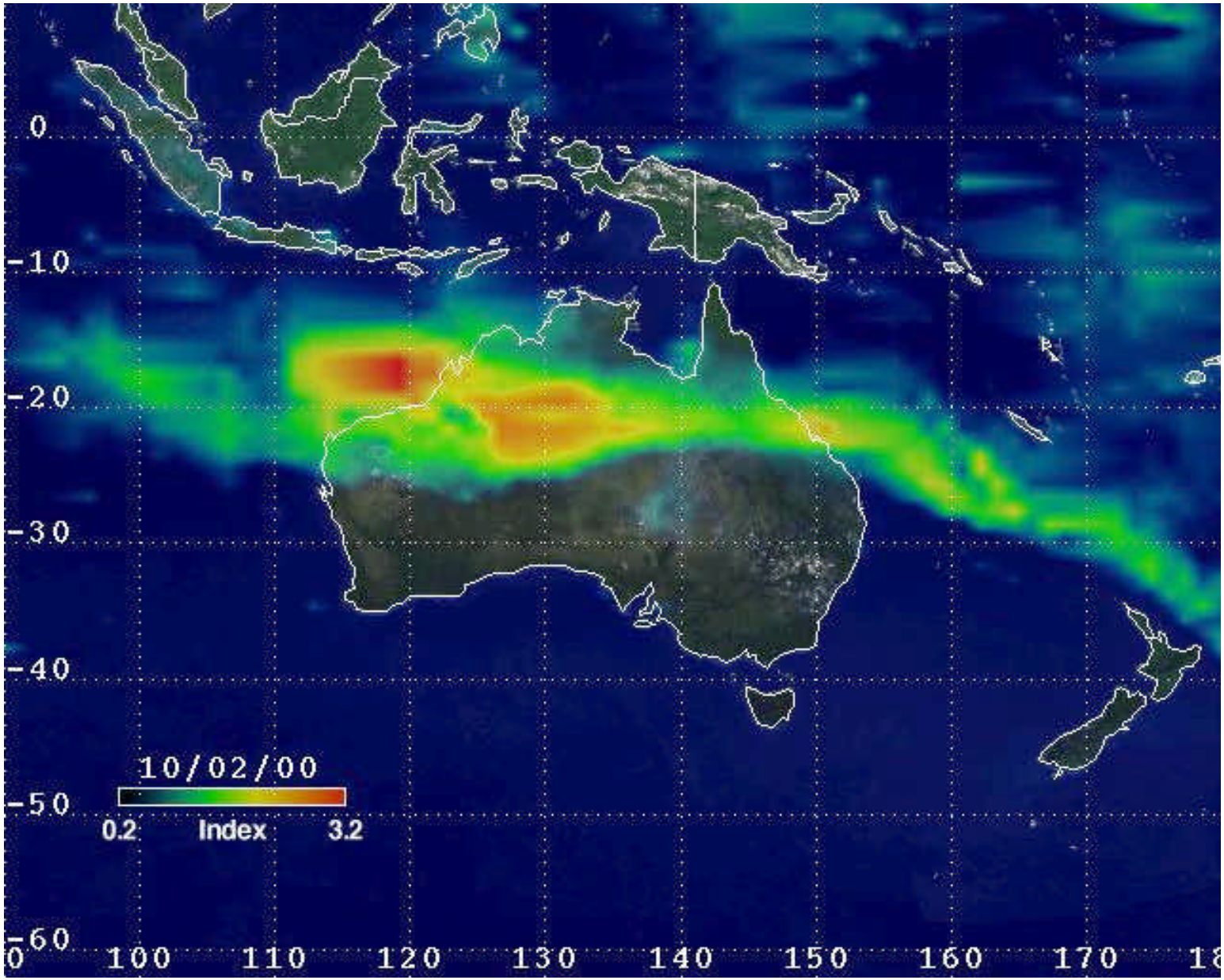


Oct 2, 2000

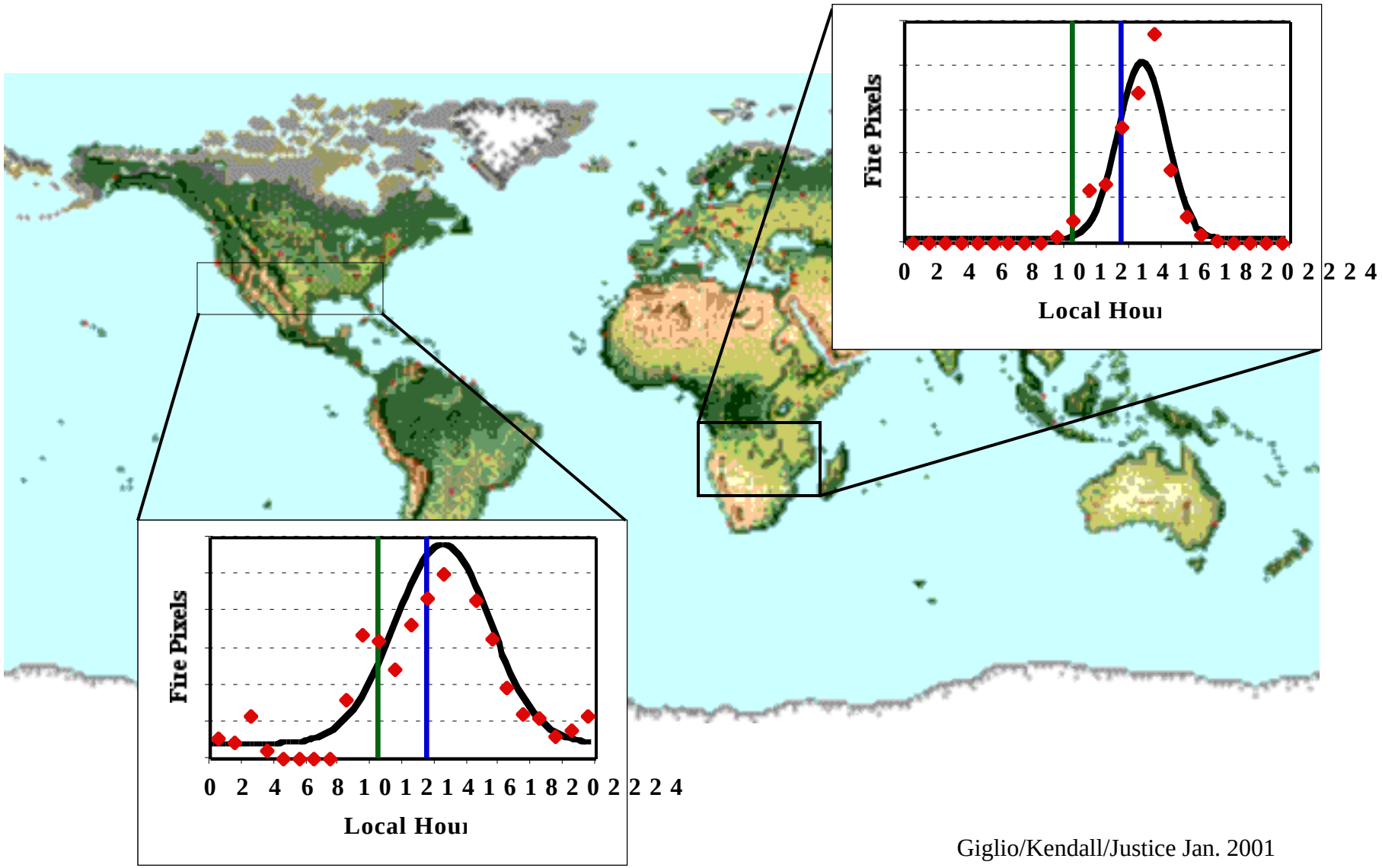
MODIS Fire Pixels – N.W. Australia (Oct 2, 2000)



TOMS Aerosol Index (Oct 2)

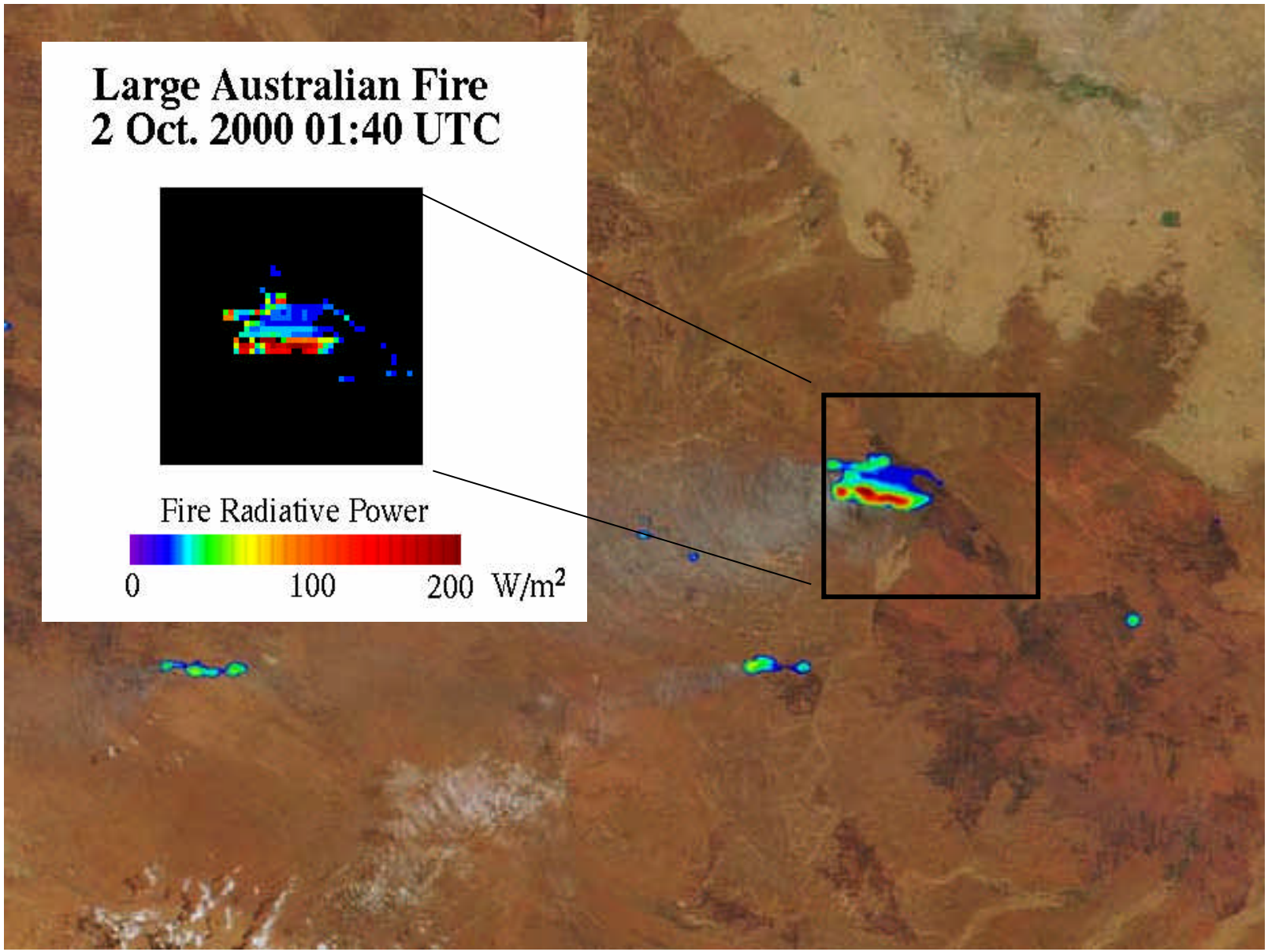


TRMM VIRS-Derived Diurnal Burning Cycle (July)



Giglio/Kendall/Justice Jan. 2001

MODIS Fire Energy



Modland/Giglio

MODIS Fire Product QA Status

- **Algorithm performing reasonably well although product quality has been degraded due to instrument problems**
- **Local overpass time tends to be early for observation of active fires in some areas**
- **QA Status given on the MODLAND QA WWW Site**
  - **//modland.nascom.nasa.gove/QAWWW/gahome.html**

Release of MODIS Fire Products

Product	Release Date
L3 8-Day, Global Browse	13 Oct. 2000
L2, L2G, L3 Daily	Nov. 2000
Burned Area	Spring 2001
L3 CMG	?
Experimental L3 Global	?

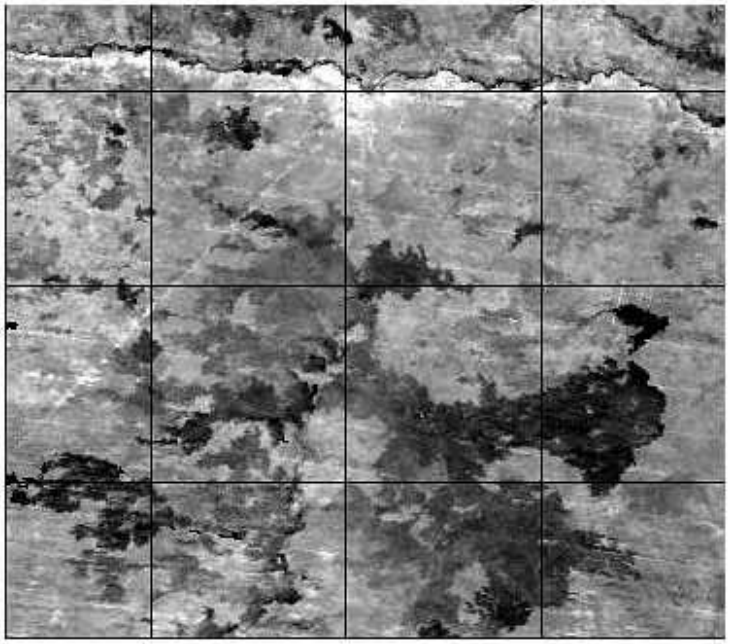
- **L3 Climate Modeling Group - Monthly 10 km and 0.5º gridded statistical summaries**
  - **smoldering ratio (flaming/smoldering/mixed)**
  - **fire radiative power**
- **Experimental Burned Area Product**
  - **input to emissions modeling community (SAFARI 2000)**
- **Combined TERRA/AQUA Fire Product (Dec 2001?)**
  - **Provide 4 observations per day**

Fire Product Distribution

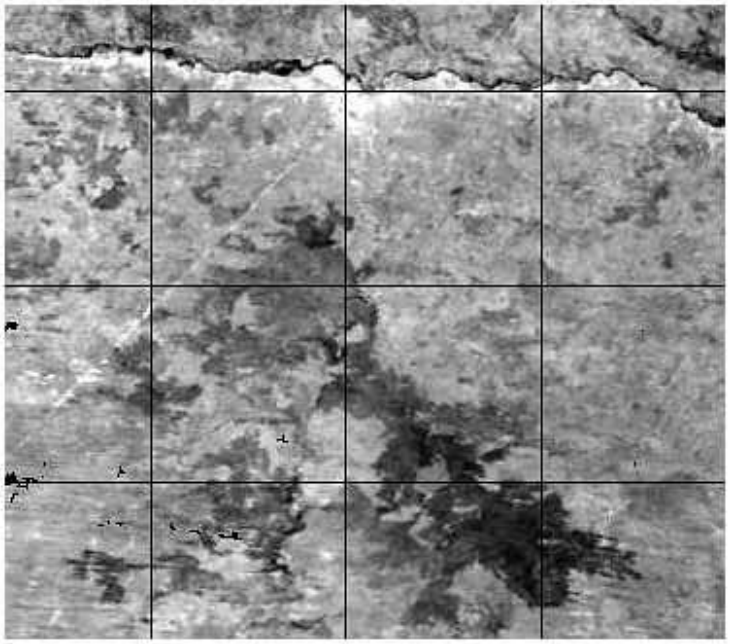
- **MODIS Level 1 data available since April from GSFC DAAC**
- **Access to L3 Fire Data sets via ftp through EDC DAAC**
- **Earth Observing System Data Gateway (EDG) interface**
  - **Search against spatial and temporal parameters.**
  - **Search against metadata and quality flags.**
  - **Not yet fully functional.**
- **Data free via. FTP**

MODIS burned-area product (experimental algorithm)

- **Algorithm operates on multi-temporal data at the pixel level**
- **Removes the need for reflectance thresholds which are sensitive to the spatial and temporal variations of burned areas**
- **Takes advantage of the bi-directional reflectance (BRDF) properties of most natural surfaces observed by wide field of view sensors from optical to thermal infrared wavelength**
- **Algorithm labels burn scar pixels as those where change is detected in a consistent manner for a specified number of days**
- **Residual cloud, sub-pixel cloud, cloud and relief shadow, and any other bad quality data are removed through use of this temporal consistency constraint.**
- **Algorithm being run for Southern Africa using MODIS 500m 0.86mm, 1.24mm or 1.64mm land surface reflectance time-series**



Observed 1.24 micron reflectance (500m) day 275



BRDF predicted 1.24 micron reflectance (500m) day 275

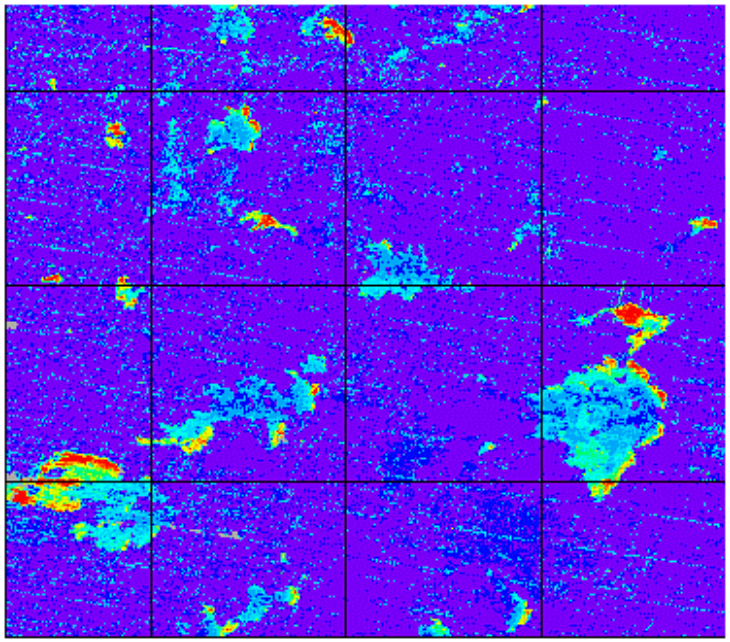
Illustration of a single step of the moving window - Angola/Namibian Border

Top left **MODIS reflectance day 275**

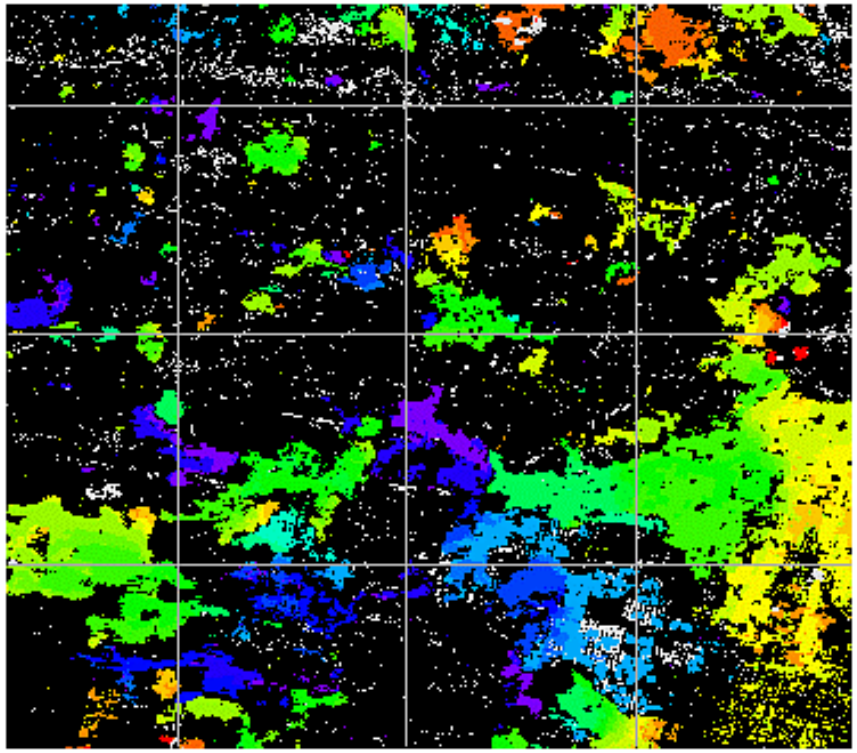
Top Right **BRDF day 275 predicted reflectance computed from previous 16 days**

Bottom **Z-score (change probability)**

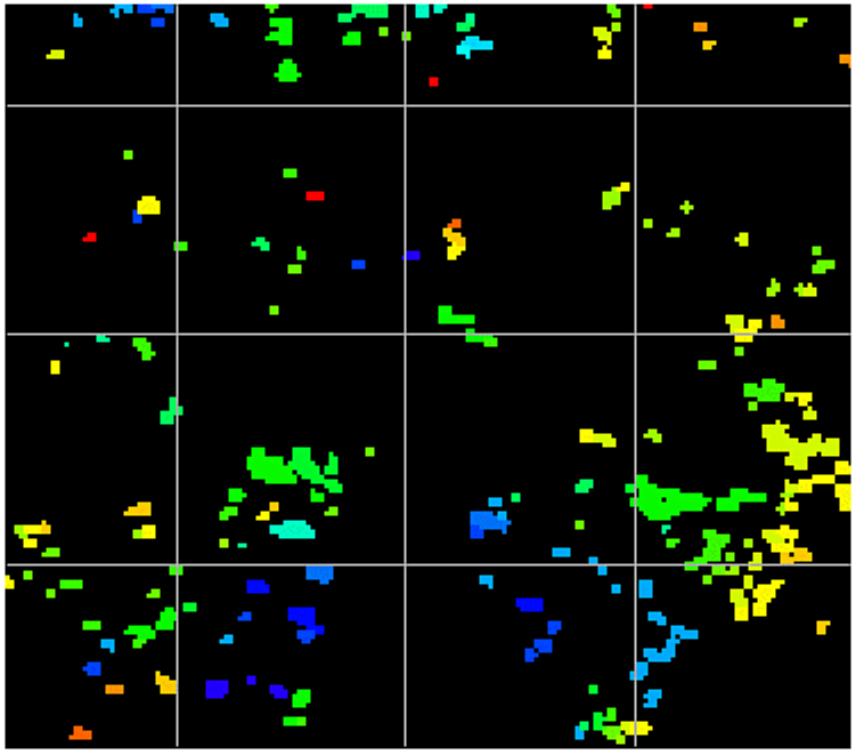
(purple and blue < 1.0, red > 5.0)



Z−score 1.24 micron reflectance (500m) day 275



Burn location and occurrence (500m) days 249–290



Active fire location and occurrence (1km) days 249–290

Left **burned area algorithm results -> burning over days 249-290 (500m)**

Right **temporal composite of MODIS day and night active fires detected over same period (1km)**

<u>Key</u>

purple - beginning of the time series (day 249)

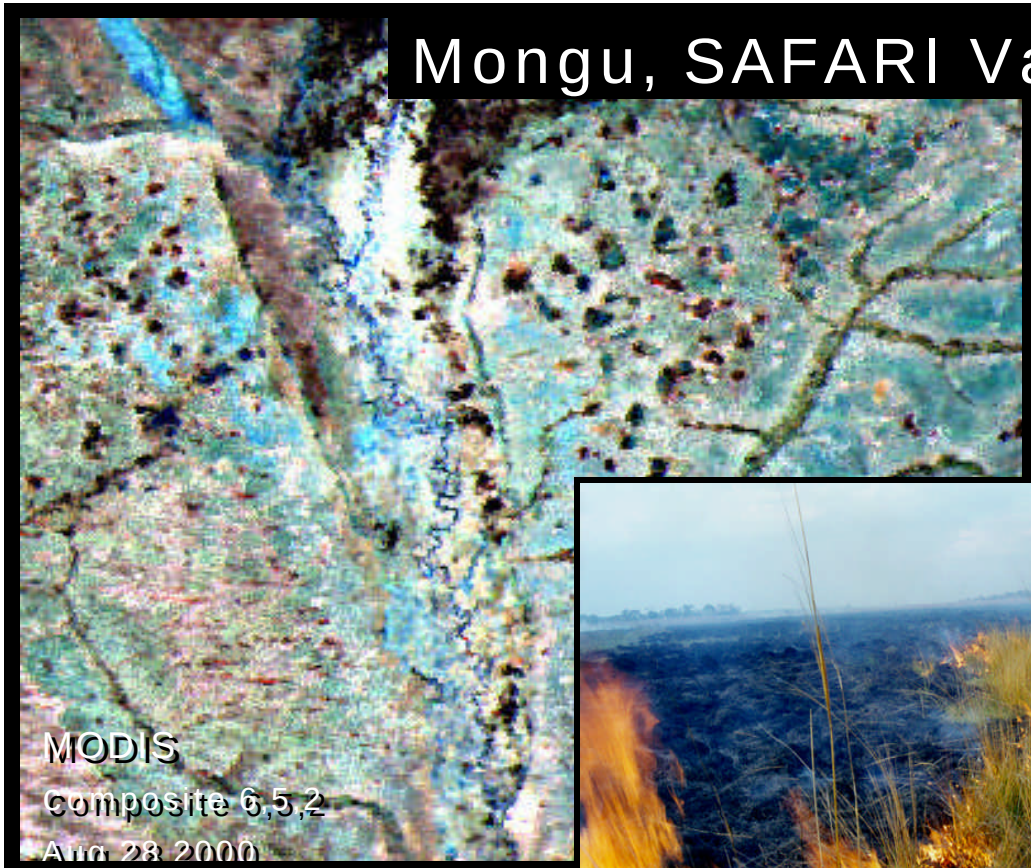
red - end of time series (day 290)

white - insufficient data in the time series to make a burning decision

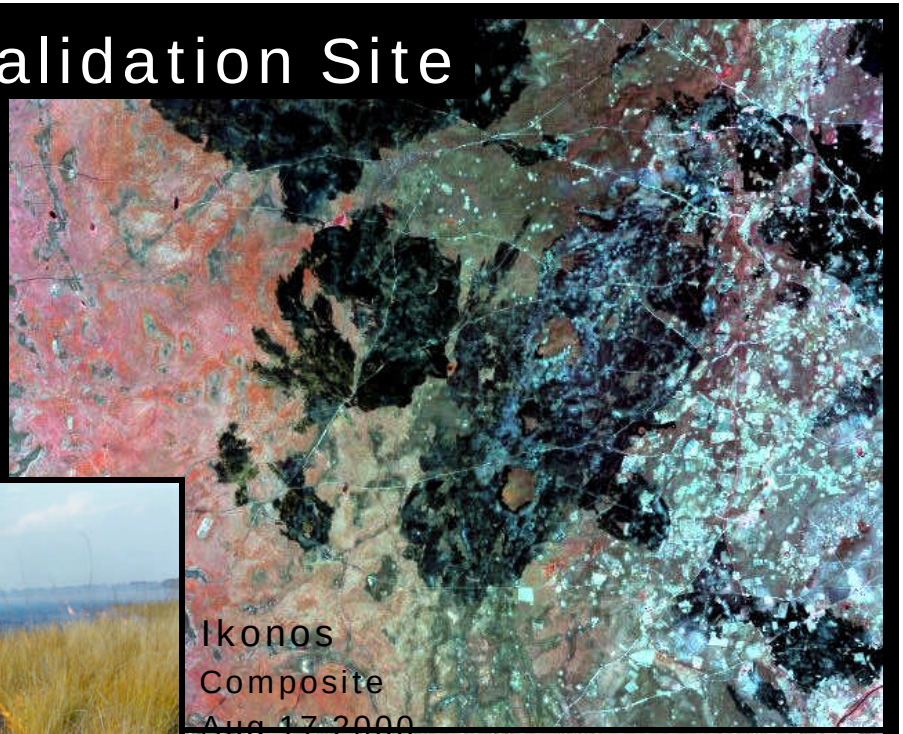
Fire Product Validation

- **Primary active fire validation measurements include:**
  - **Field surveys,**
  - **Airborne imagery – MAS**
  - **Fine and high-resolution satellite imagery (ASTER, L7)**
- **Initial Fire and Burn Scar validation efforts are being conducted through the SAFARI 2000 initiative using a network of regional collaborators:**
  - **SAFARI MAS active fires,**
  - **SAFARI Landsat-7 Burned Area w. Miombo Science Network**
  - **ASTER – contemporaneous**
  - **MODIS/AVHRR/TRMM/ATSR inter-comparisons**
- **Collaboration with W. M. Hao / Darold Ward - NASA EOS Validation investigation on Montana/Utah Fires, through USFS/Canadian Forest Service Fire Record**
- **International fire product validation coordination through the CEOS Cal/Val subgroup on Land Product Validation – GOFC initiative.**

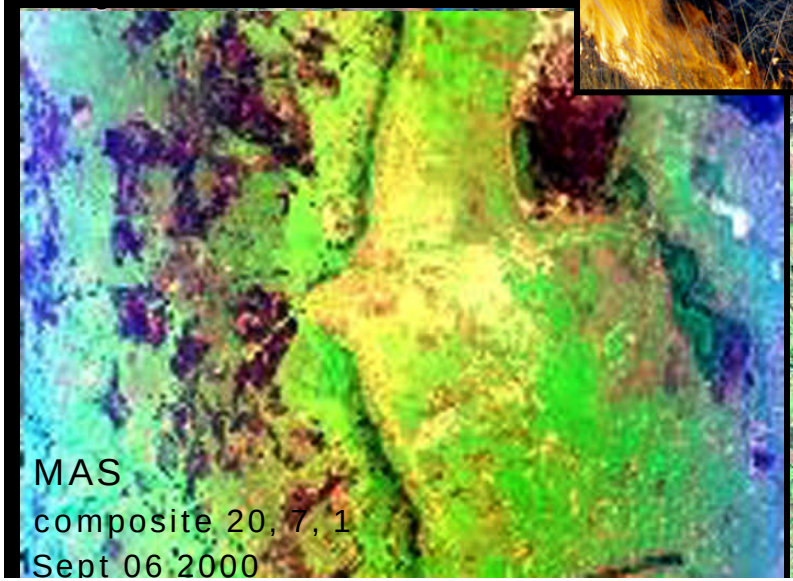
Mongu, SAFARI Validation Site



MODIS
composite 6,5,2
Aug 28 2000



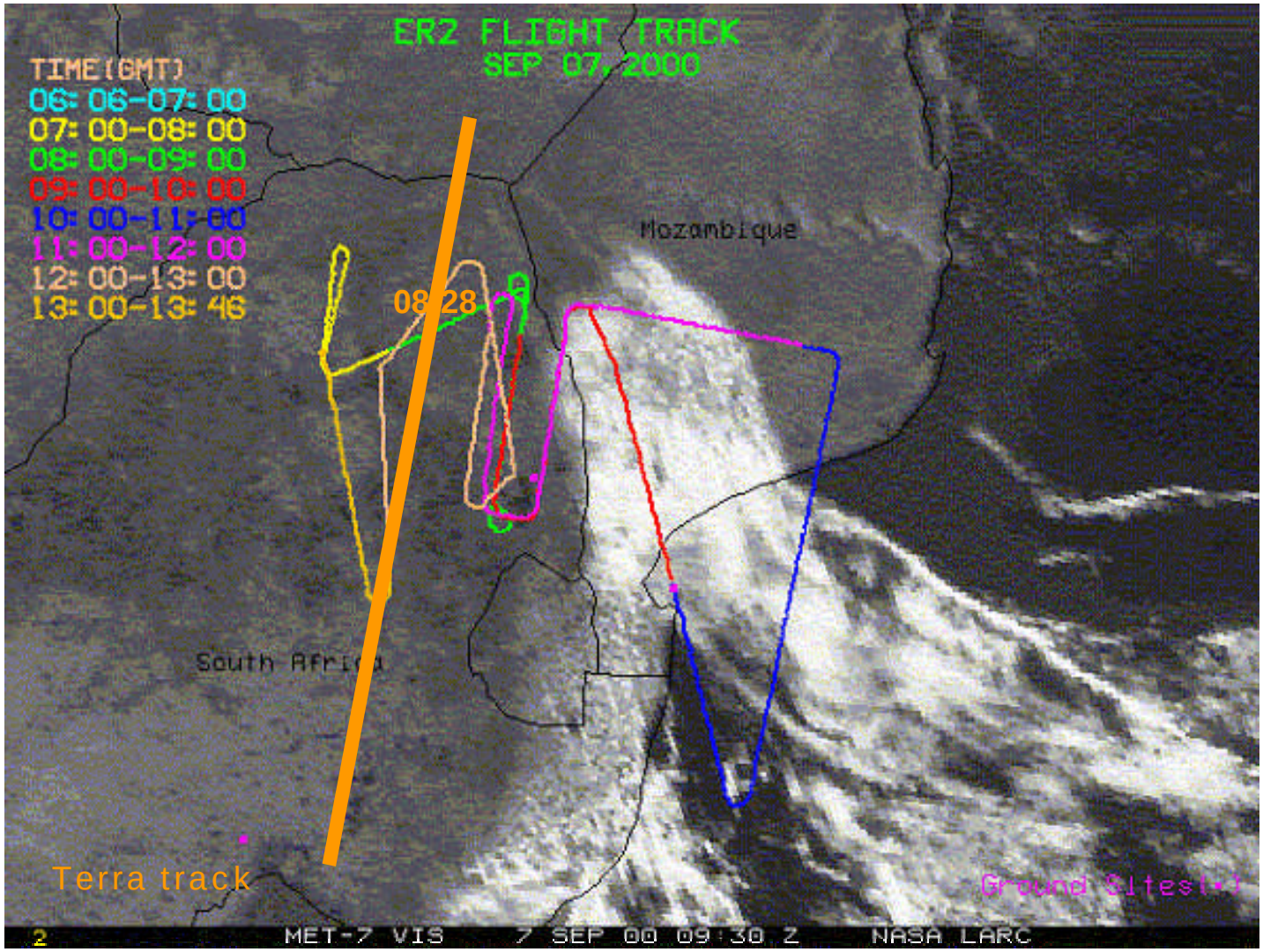
Ikonos
Composite
Aug 17 2000



MAS
composite 20, 7, 1
Sept 06 2000

Landsat 7
composite 5, 4, 3
1st Sept 2000

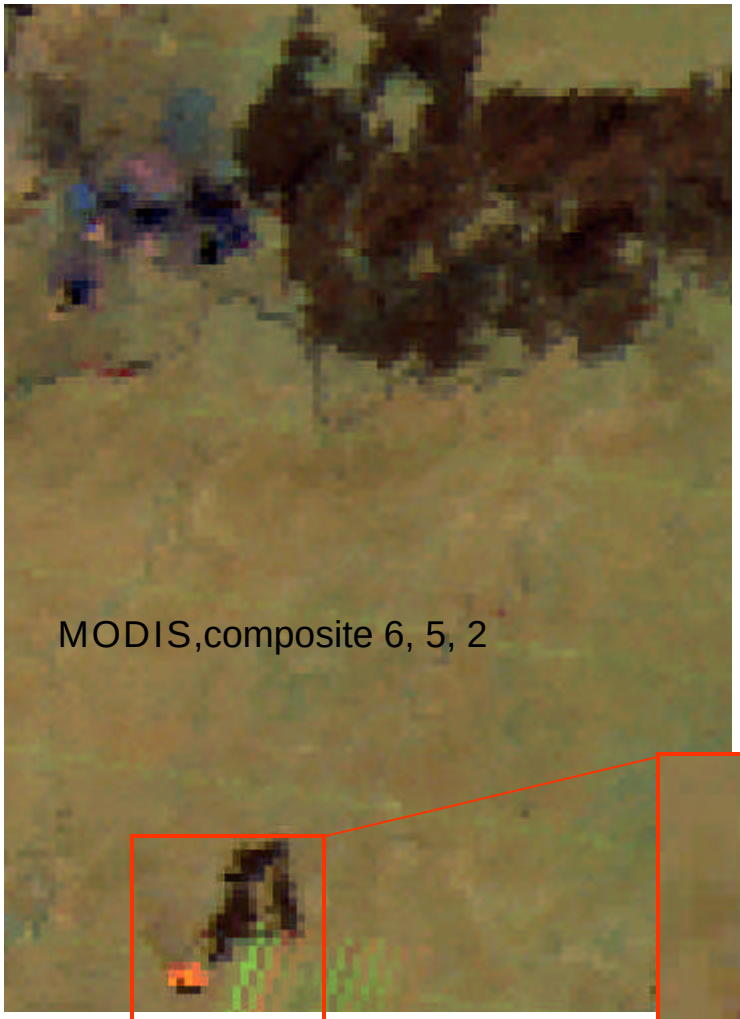
SAFARI 2K ER2 Overpass of the Timbavati controlled burn Sept. 7, 2000

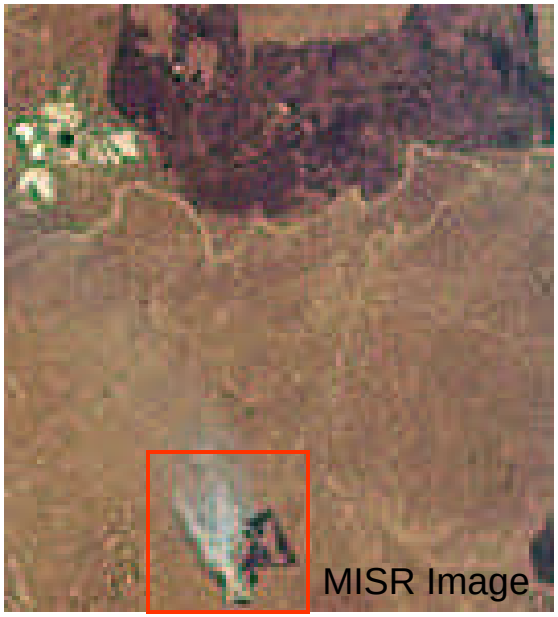


8:

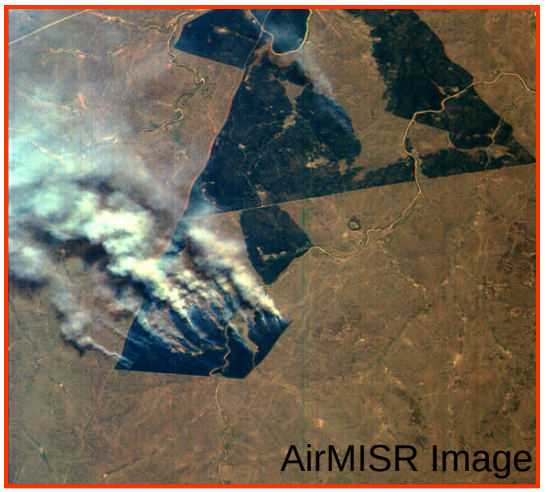
The Timbavati 1000-3000 hectare controlled burn, Sept. 7, 2000

(~24° 21’ 56”S, 31° 15’ 40”E).





TERRA
08:28UT

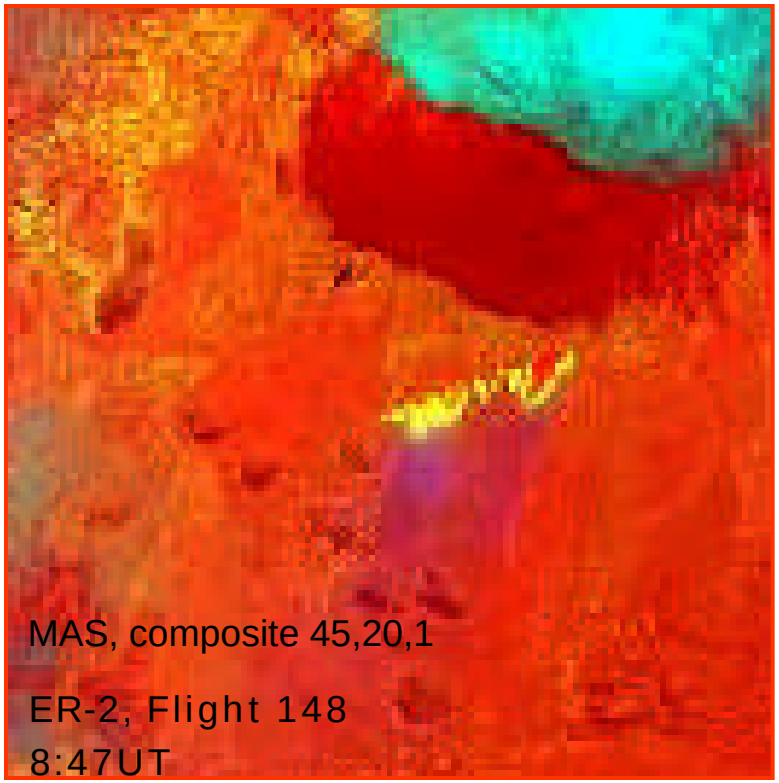


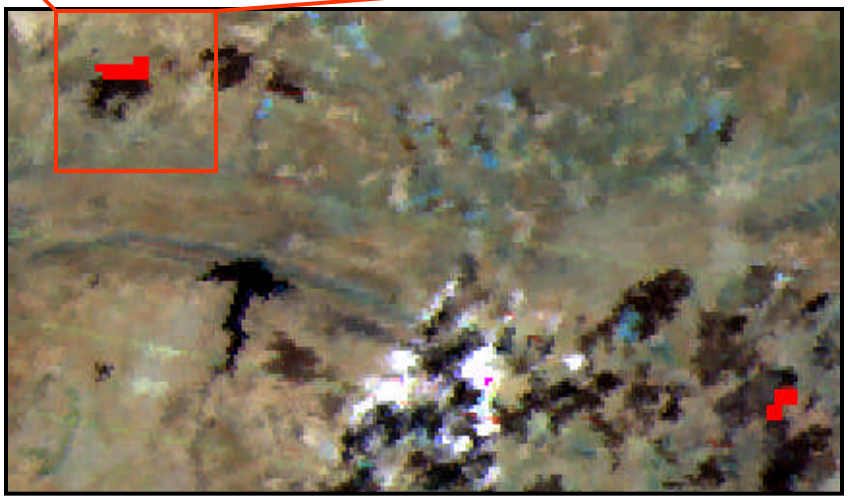
NASA ER2 Flight #00-158
08:21UT

The ER-2 observations were collected seven minutes earlier than the Terra overpass time

MODLAND/Alleaume/Swap

MODIS and MAS Aug. 20, 2000





The SAFARI 2K Madikwe prescribed fire.

Fires detected in the area for the period from Aug. 20 to Aug. 27

Red dots, from the 8-day Summary Fire Product MODIS, Composite 6, 5, 2 (Aug 22)

MODLAND/Alleaume/Swap

Concluding comments: Land Cover and Land Use Change

- MODIS Products will be crucial in addressing several of NASA's "new" Earth Science Questions.
- Several fire products now routinely being distributed.
- Most other land cover and land cover change products are dependent on several months of data (VCC - min 4 months of data, required 16 months; global land cover - 12 months).
- Validation plans well in hand, but need to continue as a substantial activity for the next two to three years. *Validation is not an instantaneous short-term process.*
- Also note 250m production remains limited and impacts some products.
- With a Dec 14th end-date several products will NOT be validated.